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DESIGN AND FABRICATION OF GRAPHITE-EPOXY BOLTED WING SKIN SPLICE SPECIMENS

R. W. Johnson and J. E. McCarty

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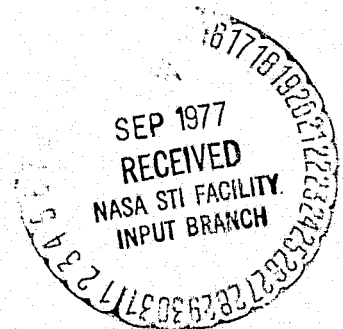
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16. Abstract The objective of this program was to design, fabricate and deliver seven graphite-epoxy bolted joint specimens for testing at the NASA-Langley Research Center. These specimens were to be representative of a side-of-body wing skin splice with a 20-year life expectancy in a commercial transport environment. Preliminary tests were performed to determine design values of bearing and net tension stresses. Based upon the information developed, a three-fastener-wide representative wing skin splice was designed for a load of 2627 KN/m (15 000 lbf/in.). One joint specimen was fabricated and tested at NASA. The wing skin splice failed at 106% of design ultimate load. This joint design achieved all static load objectives. Fabrication of six specimens, together with their loading fixtures, was completed, and the specimens were delivered to NASA-LRC.					
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DESIGN AND FABRICATION OF GRAPHITE-EPOXY BOLTED WING SKIN SPLICE SPECIMENS

R. W. Johnson and J. E. McCarty
Boeing Commercial Airplane Company

1.0 SUMMARY AND INTRODUCTION

The technology of bolted joints in composite structural components has been under active R&D efforts for several years. Design information is now sufficiently advanced for static strength so that further considerations of long-term durability under environmental exposure and cyclic loading spectra associated with commercial transport aircraft need to be explored. Detailed joint designs that consider these influences on the basic static strength will provide the basis for fabricating replicate test specimens for long-duration environmental testing.

The objective of this program was to design, fabricate, and deliver seven graphite-epoxy bolted joint specimens for testing at the NASA-Langley Research Center. These specimens were to be representative of a side-of-body wing skin splice with a 20-year life expectancy in a commercial transport environment.

During this program, specimens that contained unloaded holes and single- and double-row loaded fasteners were designed and tested to provide bearing and net area stress values for final design of the wing splice. In addition, tests were performed to determine the effect on bearing and net area stresses of varying the specimen width-to-fastener-diameter ratio.

Based upon the information developed during the various preliminary joint tests, a three-fastener-wide representative wing skin splice was designed for a load of 2627 kN/m (15 000 lbf/in.). One joint specimen was fabricated from the design and tested at NASA. The wing skin splice achieved an ultimate load of 534 kN (120 000 lbf). The estimated ultimate load was 500 kN (112 500 lbf) which resulted in an actual-to-predicted load ratio of 1.067.

This joint design achieved all static load objectives. Fabrication of the remaining six specimens, together with their loading fixtures, was completed, and the specimens were delivered to NASA-LRC.

As part of the contract requirements a typical fatigue spectrum was developed for this wing skin splice. The fatigue information and a suggested spectrum is contained in appendix A.

2.0 DESIGN GROUND RULES

The following set of design ground rules was established at the start of the program:

1. The final two-row joint specimen will contain simple splice plates. No attempt will be made to taper either the skin laminate or the splice plate in the splice area.
2. The joint will be completely symmetric to minimize eccentricities.
3. The final joint will taper in thickness away from the splice to a representative basic wing skin thickness.
4. The basic wing skin will be designed to an end load of 2627 kN/m (15 000 lbf/in.).
5. The laminate orientation for the basic skin will be approximately:

$$\begin{array}{l} 0^{\circ}-35\% \\ \pm 45^{\circ}-50\% \\ 90^{\circ}-15\% \end{array}$$

This orientation was selected since it produces an extensional and shear modulus ratio that is considered typical for sweptwing subsonic commercial transport aircraft.

6. The material selected for this test program will be T300/5209 in both unidirectional tape and cloth forms. These materials are defined as:
 - a. Unidirectional tape: T300/5209, 0.127-mm (0.005-in.) nominal thickness
 - b. Woven cloth: T300/5209-8 harness satin, 0.33-mm (0.013-in.) nominal thickness
7. The maximum allowable tension strain in the basic wing skin will be limited to 0.005 mm/mm. This strain limitation combined with the defined orientation and end load results in the following values:

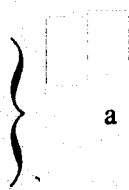
a. Design end load	$P = 2627 \text{ kN/m (15 000 lb/in.)}$	
b. Critical strain	$e_{CR} = 0.005 \text{ mm/mm}$	
c. Extensional modulus	$E = 55.2 \text{ GPa (8.0 x 10}^6 \text{ psi)}$	} Values from reference 1
d. Shear modulus	$G = 17.9 \text{ GPa (2.6 x 10}^6 \text{ psi)}$	
e. Ultimate design tension stress	$F_{ult} = 275.8 \text{ MPa (40 000 psi)}$	
f. Skin thickness	$t_s = 9.525 \text{ mm (0.375 in.)}$	

8. The basic skin laminate will contain a combination of 0.33-mm (0.013-in.) thick graphite cloth and 0.127-mm (0.005-in.) thick graphite unidirectional tape. With the defined orientation and thickness, the following practical layup results:

a. 14 plies cloth, $\pm 45^\circ$

b. 8 plies, cloth, $0^\circ/90^\circ$

c. 16 plies, tape, 0°



The graphite plies will be assembled in a symmetric layup.

9. The padup in the joint area will be accomplished with 0.33-mm (0.013-in.) thick graphite cloth and 0.127-mm (0.005-in.) thick unidirectional tape. The laminate orientation in the joint will be similar to that in the basic skin.
10. The symmetrical splice plates will be approximately one-half the thickness of the padded skin and will contain approximately the same orientation percentages.

^aVendor's data and Boeing test data indicate that cloth laminate strength and modulus are not significantly different than tape.

3.0 DESIGN APPROACH

The approach used in this program was to design and test a series of specimens to determine design values of net area and bearing stress. Single-bolt splice tests and unloaded hole strength tests were performed to provide the design data.

The single-bolt splice tests produced net tension and bearing stress values for a 100% loaded hole, and the unloaded hole strength tests produced net tension stresses for a 100% bypass case or zero load transfer. By combining these test results, the net tension value for a 50% load transfer case, such as occurs for a symmetrically loaded two-row joint, will be as shown in figure 1. A joint concept test specimen was designed on the assumption of a linear relationship between net area and percent load transfer. The validity of this assumption has been experimentally verified by the work of Whitman, Shyprykevich, and Whiteside of Grumman Aerospace Corporation (ref. 2). The joint concept test specimen was fabricated and subsequently tested at NASA-LRC, and the results verified the linear relationship between net area stress and percent load transfer.

At this point in the program, additional testing was performed, under a contract modification, to determine the effect of varying the specimen width-to-fastener-diameter ratio (W/D).

A proof-of-concept specimen was designed based upon the test data. This specimen was fabricated at Boeing and was delivered to NASA-LRC for test. The specimen was tested, and the results verified the design approach.

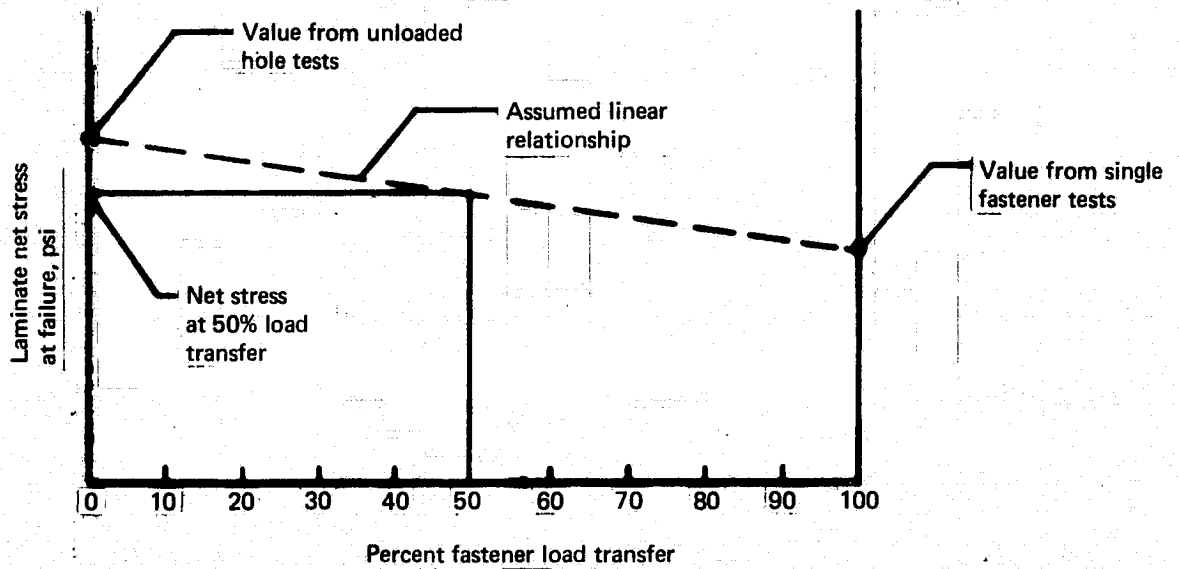


Figure 1.—Laminare Net Area Stress Versus Percent Load Transfer

4.0 TEST SPECIMEN DESIGN AND FABRICATION

The specimens that were designed and fabricated during this program are summarized in table 1, and the design drawings are presented in appendix B. The design drawings contain a full description of the specimens. All specimens contain the laminate orientation that was specified in section 2.0; namely, 35% 0°, 50% ±45°, and 15% 90°. The layup sequence of the cloth and unidirectional tape is specified in each drawing.

Receiving inspection tests were conducted for the T300/5209 tape and cloth material. The results of these tests are presented in appendix C.

All specimens were fabricated according to the Boeing Process Specification XBAC 5562. No debulking or partial bleeding was used during fabrication of the laminates. The cure cycle used for the T300/5209 material is defined in table 2.

All laminates were subjected to X-ray and ultrasonic inspection. The X-ray and ultrasonic records were reviewed, and all laminates were free of defects.

All fastener holes were made by drilling a 0.794-mm-dia (1/32-in.) undersize pilot hole using a standard high-speed steel drill at 11.5 rad/sec (110 rpm) and reaming the hole to size with a carbide-tipped router bit at 25.6 rad/sec (245 rpm). All hole drilling was done by hand with no coolant. The bolt holes were measured after the final ream operation, and all holes were within the diameter tolerances specified in the drawings.

The graphite laminates were rough-cut with a bandsaw, and final machining was performed with standard carbide milling machine tools.

Photographs of completed design development specimens are presented in figures 2 through 5. Prior to fabrication of the laminates for the final wing splice joint, a fabrication feasibility specimen was made to determine the amount of thermal distortion that could be expected because of the tapered geometry. The test laminate, as shown in figure 6, indicated no thermal distortion. The 2-in.-wide part was then cut in half, and the tapered sections were structurally bonded back-to-back, with FM 123-2 cured at 394 K (250° F), to form a 25.4-mm (1.0-in.) wide section of the preliminary joint design as shown in figure 7. This manufacturing exercise demonstrated the feasibility of fabricating the final joints in this manner. Using this procedure, the joints would be completely symmetric, and an even distribution of load in each splice plate would be achieved.

The final wing joint splice specimen was designed with the 9.525-mm (3/8-in.) diameter fastener at a W/D of 6.67. The fastener size and spacing was selected to provide a positive margin for fastener shear at the design load of 2627 kN/m (15 000 lbf/in.). The test results of varying the W/D ratios indicated that some bearing deformations would occur at a W/D of 6.67 at static ultimate load. This was considered advantageous since uniform load distribution would be ensured among all fasteners in the splice.

The final wing splice specimen was fabricated to the design drawing (app. B, fig. 26, drawing 69-60930 (rev. A)). Each -2 laminate was laid up, cured, and then bonded back-to-back to

Table 1.—List of Design Drawings

Drawing no.	Description	Appendix B Figure
69-60927	Single row graphite bolted joint	20
69-60928	Unloaded hole graphite specimen	21
69-60929	Graphite basic material specimen	22
69-60931	Double row joint concept specimen	23
69-60933	W/D of 8-graphite bolted joint	24
69-60934	W/D of 6.67-graphite bolted joint	25
69-60930(A)	Graphite bolted wing splice specimen	26
69-60935(B)	Static test machine grip assembly	27
69-60937	Fatigue test machine load bar	28

Table 2.—Cure Cycle for T300/5209 Graphite

SI units	U.S. customary units
1. Maintain 559 mm Hg vacuum minimum.	1. Maintain 22 in. Hg vacuum minimum.
2. Heat assembly to 353 ± 2.8 K at 2.2 to 3.3 K/minute.	2. Heat assembly to $175^\circ \pm 5^\circ$ F at 4° to 6° F/minute.
3. Hold at 353 ± 2.8 K for 30^{+0}_{-5} minutes.	3. Hold at $175^\circ \pm 5^\circ$ F for 30^{+0}_{-5} minutes.
4. Apply $0.59^{+0.1}_{-0}$ MPA for laminates. Apply $0.31^{+0.01}_{-0}$ MPA for sandwich.	4. Apply 85^{+15}_{-0} psig for laminates. Apply 45 ± 5 psig for sandwich.
5. Vent bag when pressure reaches $0.14^{+0.07}_{-0}$ MPA.	5. Vent bag when pressure reaches 20^{+10}_{-0} psig.
6. Heat from 353 to 400 ± 2.8 K at 2.2 to 3.3 K/minute.	6. Heat from 175° to $260^\circ \pm 5^\circ$ F at 4° to 6° F/minute.
7. Hold 95 ± 5 minutes at 400 ± 2.8 K.	7. Hold 95 ± 5 minutes at $260^\circ \pm 5^\circ$ F.
8. Cool to 333 K or below under pressure.	8. Cool to 140° F or below under pressure.

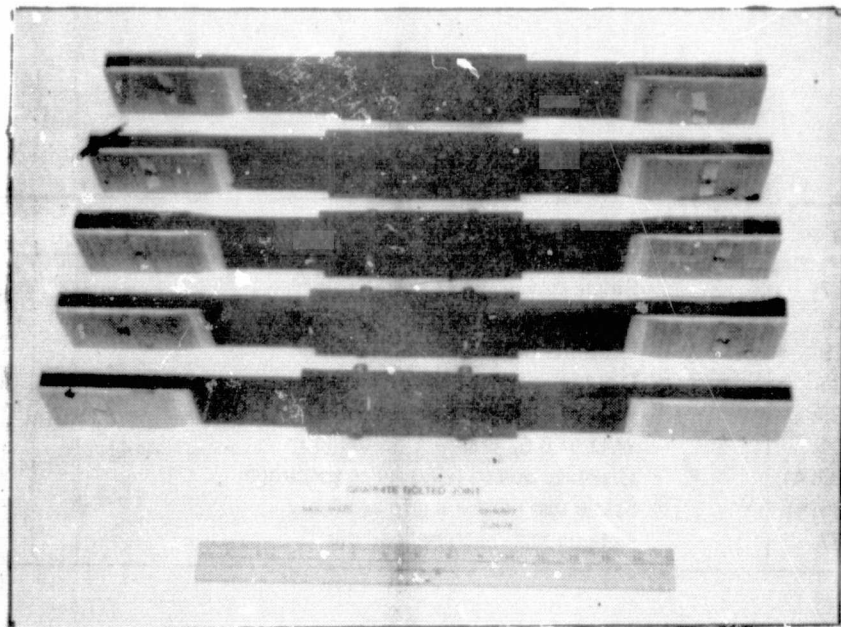


Figure 2.—Single-Row Graphite Bolted Joint, Drawing 69-60927

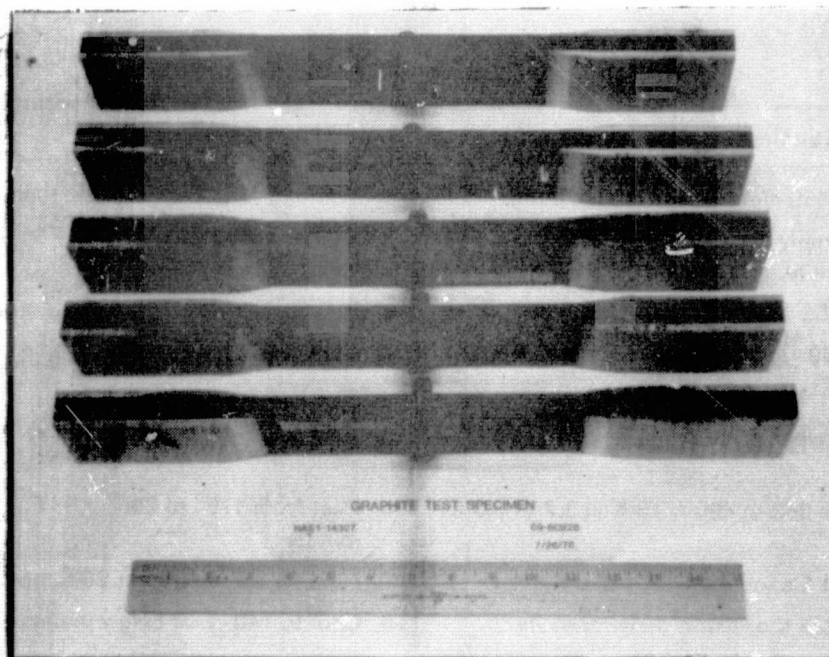


Figure 3.—Unloaded Hole Graphite Test Specimen, Drawing 69-60928

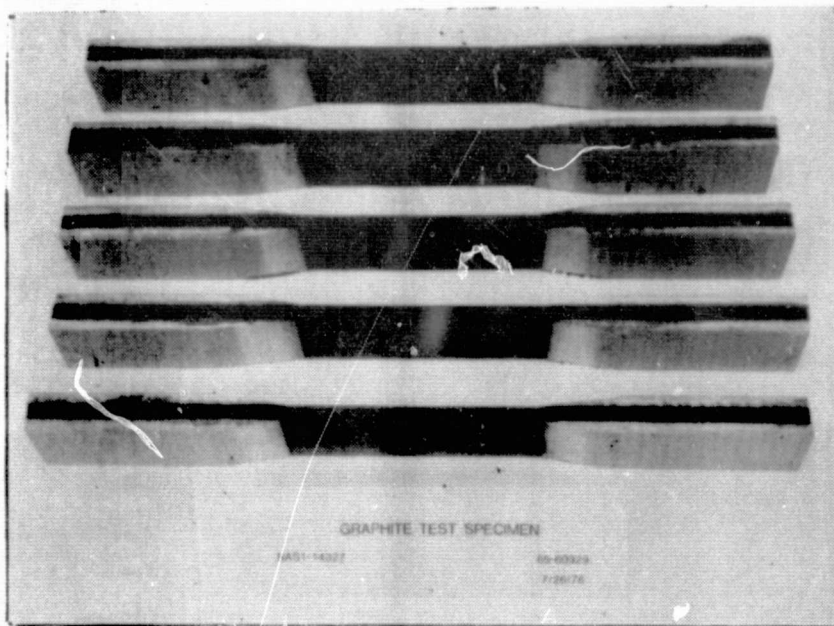


Figure 4.—Basic Material Graphite Test Specimen, Drawing 69-60929

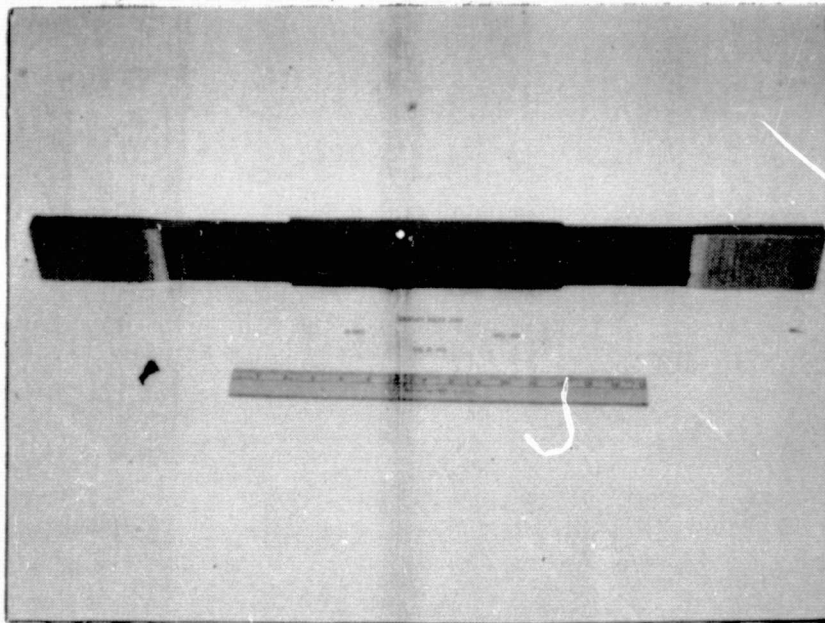


Figure 5.—Double-Row Joint Concept Graphite Test Specimen, Drawing 69-60931

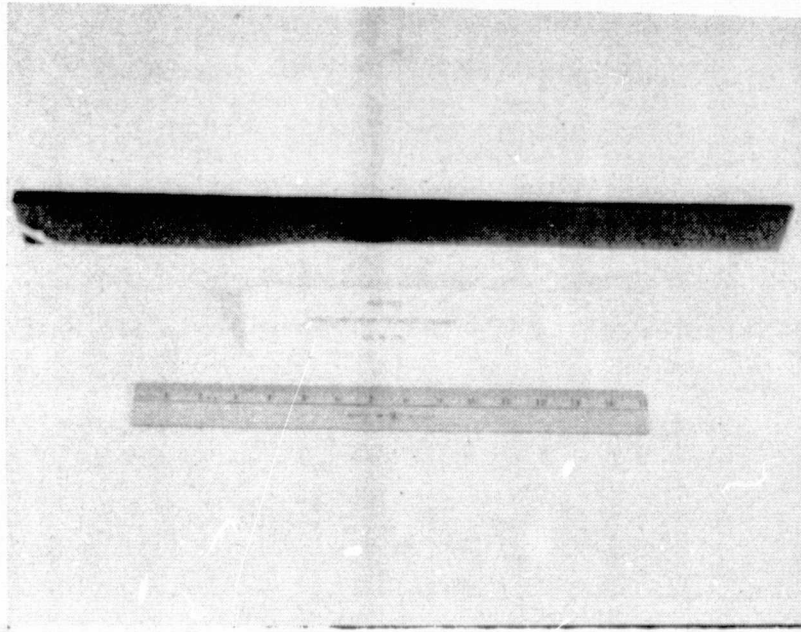


Figure 6.—Tapered Fabrication Feasibility Laminate

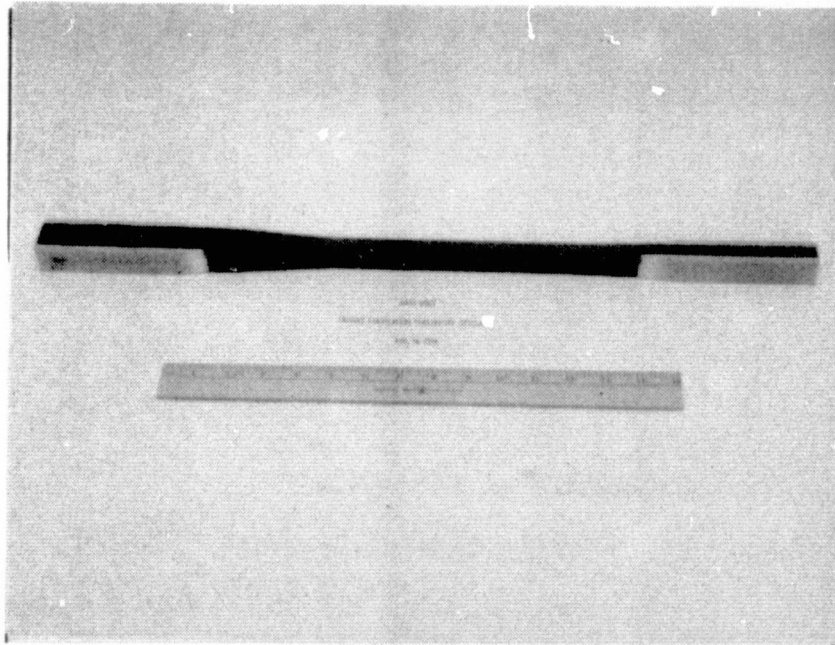


Figure 7.—Tapered Fabrication Feasibility Specimen

form the final configuration as previously explained for the feasibility specimen. The fabrication sequence for the wing splice specimen is shown in figures 8 through 11.

The design of the wing splice specimen loading plates is presented in appendix B, figure 27, drawing 69-60935 (rev. B). The loading plates were designed so that the specimen could be installed in a static test machine or a fatigue machine without altering the load plate assembly. For fatigue testing, the 69-60935-2 load tang would be replaced with the fatigue machine load bar (app. B, fig. 28, drawing 69-60937). A complete assembly of the wing splice specimen and the loading plates is shown in figure 12.

The steel loading plates were cadmium plated and painted with one primer coat and an enamel topcoat. The loading plates were bolted to the graphite specimen with polysulfide sealant between all surfaces to protect the area against moisture collection and subsequent corrosion.

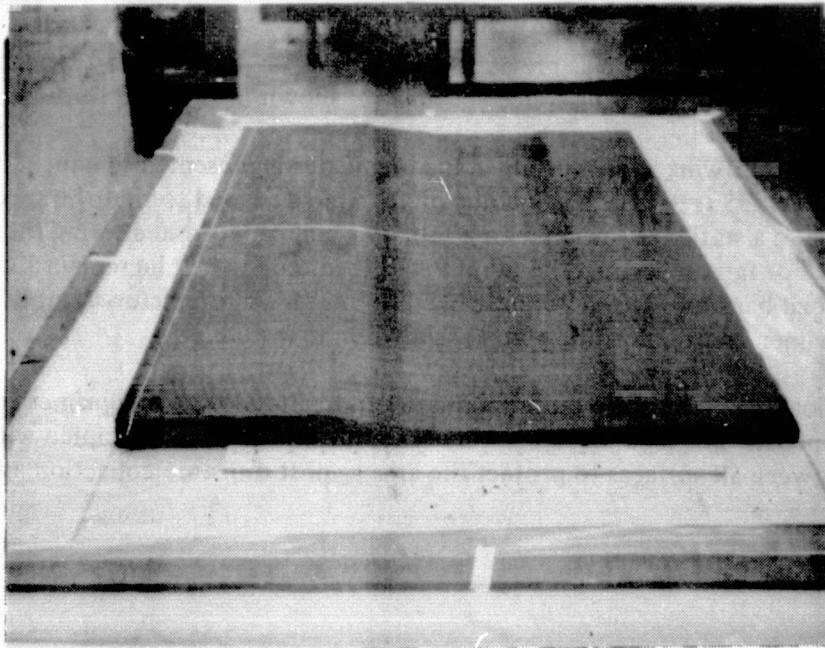


Figure 8.—Partial Layup of the 69-60930-2 Laminate

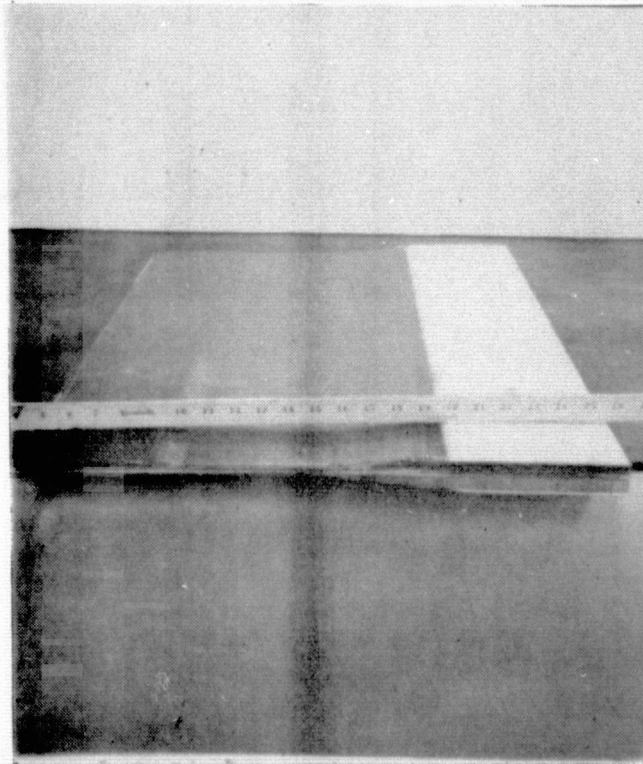


Figure 9.—Cured 69-60930-2 Laminate

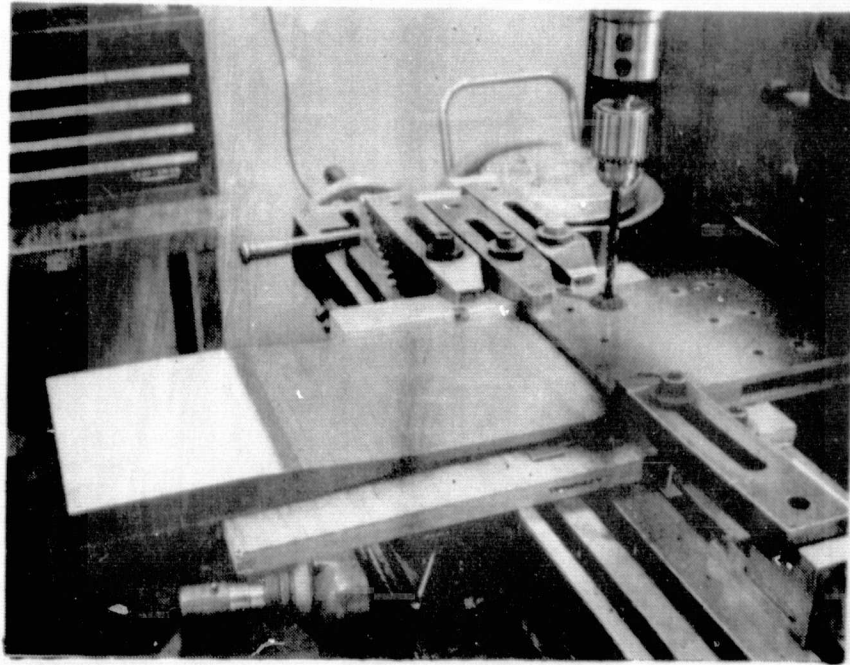


Figure 10.—Drilling of the 69-60930 Specimen

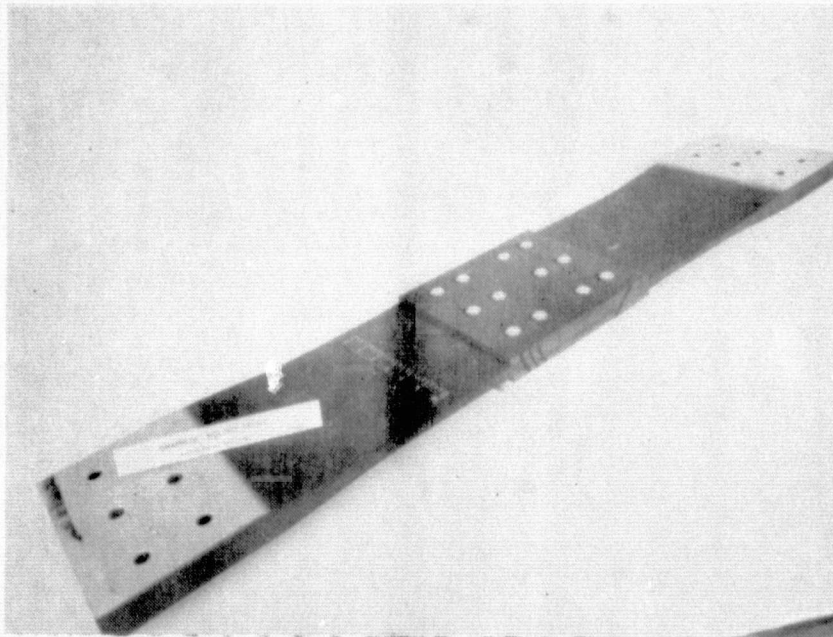


Figure 11.—Fully Assembled 69-60930 Specimen

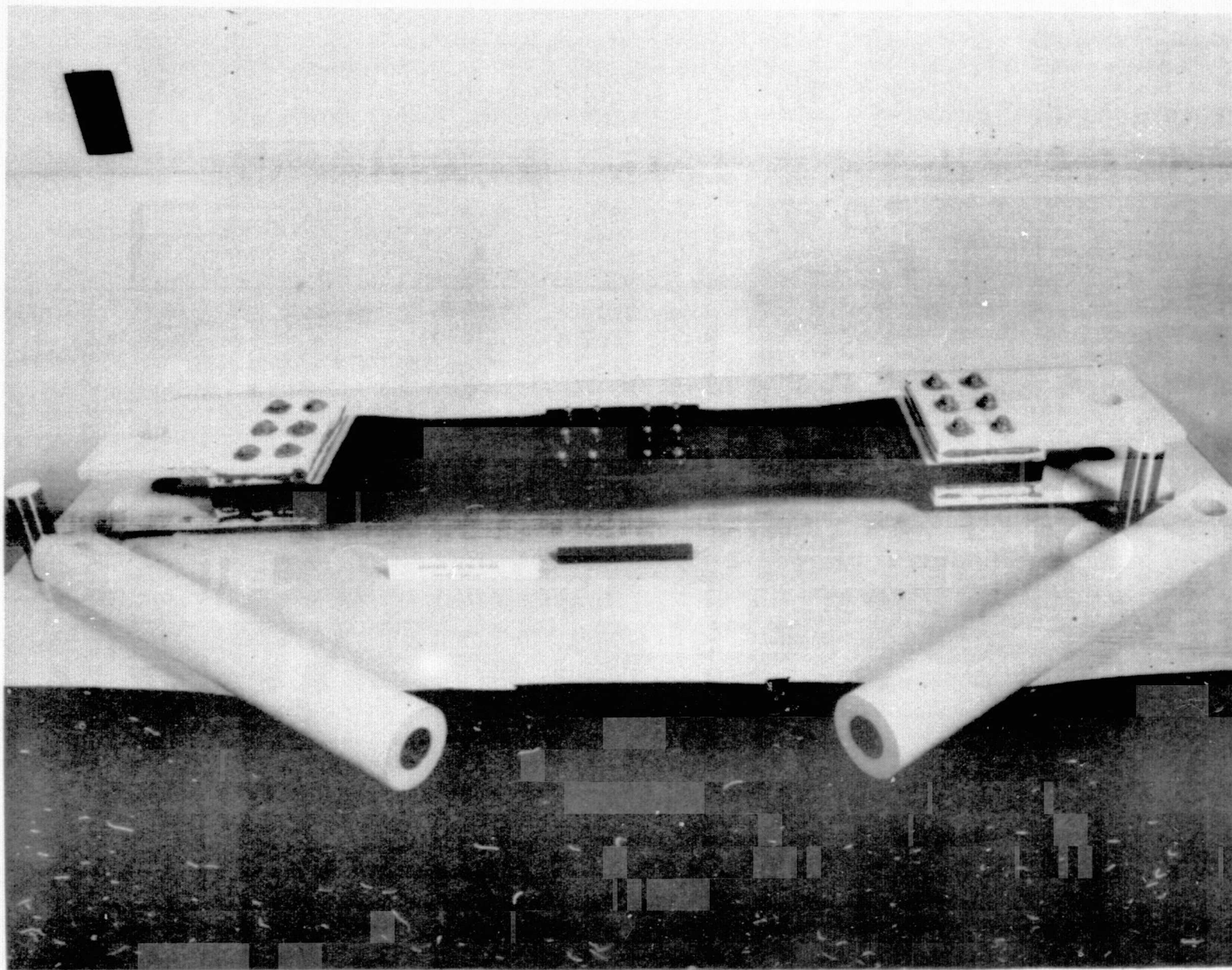


Figure 12.—Assembly of Wing Skin Splice Specimen and the Loading Plates

5.0 TEST RESULTS

The design development specimens (figs. 2, 3, and 4) were tested and evaluated. The test results are shown in table 3. The results from the basic material tests (69-60929) indicate an average modulus of 60.7 GPa (8.8×10^6 psi), which is 10% higher than given in reference 1 for the defined orientation, and the average ultimate tension stress of 491.4 MPa (71 252 psi) is 6% lower than given in reference 1 and 78% above the design stress of 275.9 MPa (40 000 psi) as defined in section 2.0.

Figure 13 contains the failure stresses from table 3 plotted against percent load transfer.

The design procedure defined in section 3.0 was performed, which resulted in a net area stress of 261.8 MPa (37 962 psi) (fig. 13). This value of net area stress was used to design the double-row joint concept specimen, 69-60931 (fig. 5). This specimen was tested at NASA-LRC. The specimen dimensions, load displacement curve, and the failure load are presented in figure 14. The specimen failed at an ultimate load of 164.6 kN (37 000 lbf), the predicted failure load was 166.8 kN (37 500 lbf) which resulted in a test-to-predicted ratio of 0.987.

To obtain a better value of net area failure stress for the double-row joint concept specimen, two additional specimens of the 69-60931 configuration were fabricated and tested under Boeing Company IR&D funds. Figure 15 shows a typical test setup. The results of these three tests produced an average net area stress of 169.8 kN (38 180 psi) and an average bearing stress at failure of 340.5 kN (76 539 psi).

Six additional specimens of configurations similar to the 69-60931 were designed, fabricated, and tested to determine the dependence of net area and bearing stresses on W/D. Table 4 contains the results from these six tests compared to the results obtained for the 69-60931 specimens. The failure process observed for the 69-60933 specimens was significant bearing deformation and final net tension failure. A typical plot of a load deflection curve for a 69-60933 specimen is shown in figure 16. Table 4 is graphically displayed in figure 17.

The manufacturing feasibility specimen (fig. 7) was tested to static tension failure. The specimen failed at a load of 109.4 kN (24 600 lbf) at a stress of 477.2 MPa (69 200 psi). This test result indicated that the designed taper rates of the final wing skin splice specimens would provide an acceptable level of stress concentration.

The final wing joint splice specimen was fabricated and delivered to NASA-LRC as a proof-of-concept specimen. Using the 9.525-mm (3/8-in.) diameter fasteners, at a W/D of 6.67, and the nominal thicknesses as shown in drawing 69-60930, the net area and bearing stresses at failure will be 225.4 (32 680) and 638.6 MPa (92 593 psi), respectively, at an ultimate design load of 500 kN (112 500 lbf). The test machine load plate assembly, drawing 69-60935 (rev. A), was also fabricated and delivered to NASA-LRC. The wing joint splice specimen was tested at NASA-LRC on December 22, 1976. The specimen failed at an ultimate load of 534 kN (120 000 lbf). The estimated failure load was 500 kN (112 500 lbf) which resulted in a ratio of actual-to-predicted load of 1.067. The joint deformations that occurred during test were monitored and recorded as shown in figure 18. The difference between the

two DCDT's was plotted as shown in figure 18. The difference curve indicated linear response in the splice area up to a load of 422.6 kN (95 kip). From 422.6 (95) to 534 kN (120 kip), the splice area exhibited approximately 0.56 mm (0.022 in.) of nonlinear response.

During the fabrication of the final six wing splice specimens, five basic material property tension coupons were fabricated and tested. These specimens were representative of the basic skin area in the 69-60930 wing splice specimen. The specimen dimensions and test values are presented in table 5. These test data show close agreement with the basic material data previously shown in table 3.

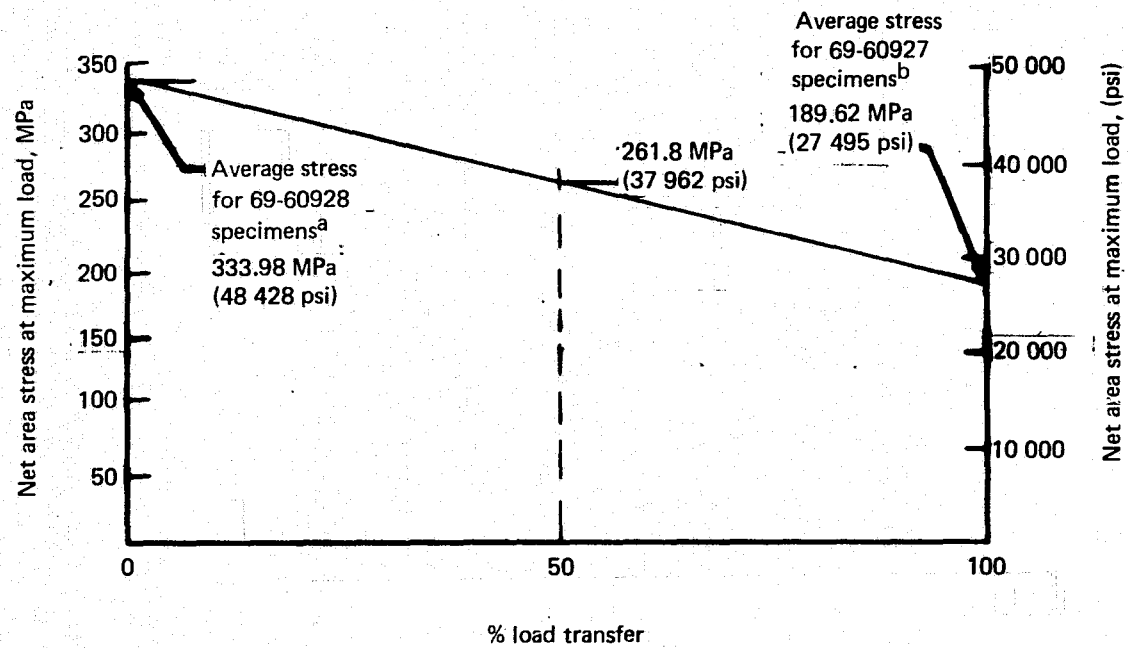


Figure 13. -Plot of Failure Stresses Versus Percent Load Transfer for Specimens With a W/D of 5

^aSpecimens failed in net tension

^bSpecimens failed in bearing

Table 3.—Test Results for the 69-60927, 69-60928, and 69-60929 Specimens

Specimen description	Specimen number	Width, mm (in.)	Thickness, mm (in.)	Gross area, mm ² (in. ²)	Net area, mm ² (in. ²)	Failure load, kN (lbf)	Gross area stress, MPa (psi)	Net area stress, MPa (psi)	Bearing stress, MPa (psi)	Failure mode
Single row graphite Bolted joint	69-60927-1	63.53 (2.501)	14.30 (0.563)	908.41 (1.408)	727.09 (1.127)	138.79 (31 200)	152.82 (22 159)	190.92 (27 684)	764.38 (110 835)	Bearing
W/D = 5	-2	63.63 (2.505)	14.40 (0.567)	916.23 (1.420)	733.55 (1.137)	138.34 (31 100)	151.04 (21 901)	188.64 (27 353)	756.55 (109 700)	Bearing
12.7-mm (0.50-in.) diameter Fastener	-3	63.65 (2.506)	14.71 (0.579)	936.32 (1.451)	749.03 (1.161)	143.68 (32 300)	153.52 (22 261)	191.87 (27 821)	769.46 (111 572)	Bearing
	-4	63.60 (2.504)	14.71 (0.579)	935.58 (1.450)	749.03 (1.161)	143.02 (32 150)	152.91 (22 172)	190.98 (27 692)	765.62 (111 015)	Bearing
	-5	63.63 (2.505)	14.15 (0.557)	900.19 (1.396)	721.29 (1.118)	133.90 (30 100)	148.70 (21 562)	185.67 (26 923)	744.70 (107 982)	Bearing
Unloaded hole graphite Specimen	69-60928-1	63.55 (2.502)	14.27 (0.562)	907.09 (1.406)	725.80 (1.125)	234.65 (52 750)	258.74 (37 518)	323.37 (46 889)	—	Net tension
W/D = 5	-2	63.58 (2.503)	14.88 (0.586)	946.26 (1.467)	757.42 (1.174)	265.79 (59 750)	280.89 (40 729)	350.99 (50 894)	—	Net tension
12.7-mm (0.50-in.) diameter Fastener	-3	63.60 (2.504)	15.16 (0.597)	964.46 (1.495)	771.61 (1.196)	266.90 (60 000)	276.79 (40 134)	345.98 (50 167)	—	Net tension
	-4	63.58 (2.503)	15.16 (0.597)	964.06 (1.494)	771.61 (1.196)	241.55 (54 300)	250.65 (36 345)	313.11 (45 401)	—	Net tension
	-5	63.58 (2.503)	14.15 (0.557)	899.47 (1.394)	720.00 (1.116)	242.21 (54 450)	269.38 (39 060)	336.48 (48 790)	—	Net tension

Specimen description	Specimen number	Width, mm (in.)	Thickness, mm (in.)	Area, mm ² (in. ²)	Failure load, kN (lbf)	Failure stress, MPa (psi)	Modulus, GPa (psi x 10 ⁶)
Graphite basic material specimen	69-60929-1	50.93 (2.005)	9.68 (0.381)	492.84 (0.764)	250.22 (56 250)	507.76 (73 626)	61.83 (8.965)
	-2	51.03 (2.009)	9.68 (0.381)	493.84 (0.765)	249.11 (56 000)	504.85 (73 203)	59.70 (8.657)
	-3	50.90 (2.004)	9.88 (0.389)	502.94 (0.779)	215.75 (48 500)	429.37 (62 259)	56.75 (8.229)
	-4	50.90 (2.004)	9.78 (0.385)	497.77 (0.772)	240.21 (54 000)	482.40 (69 948)	60.36 (8.752)
	-5	50.95 (2.006)	9.68 (0.381)	493.08 (0.764)	262.45 (59 000)	532.58 (77 225)	64.94 (9.416)

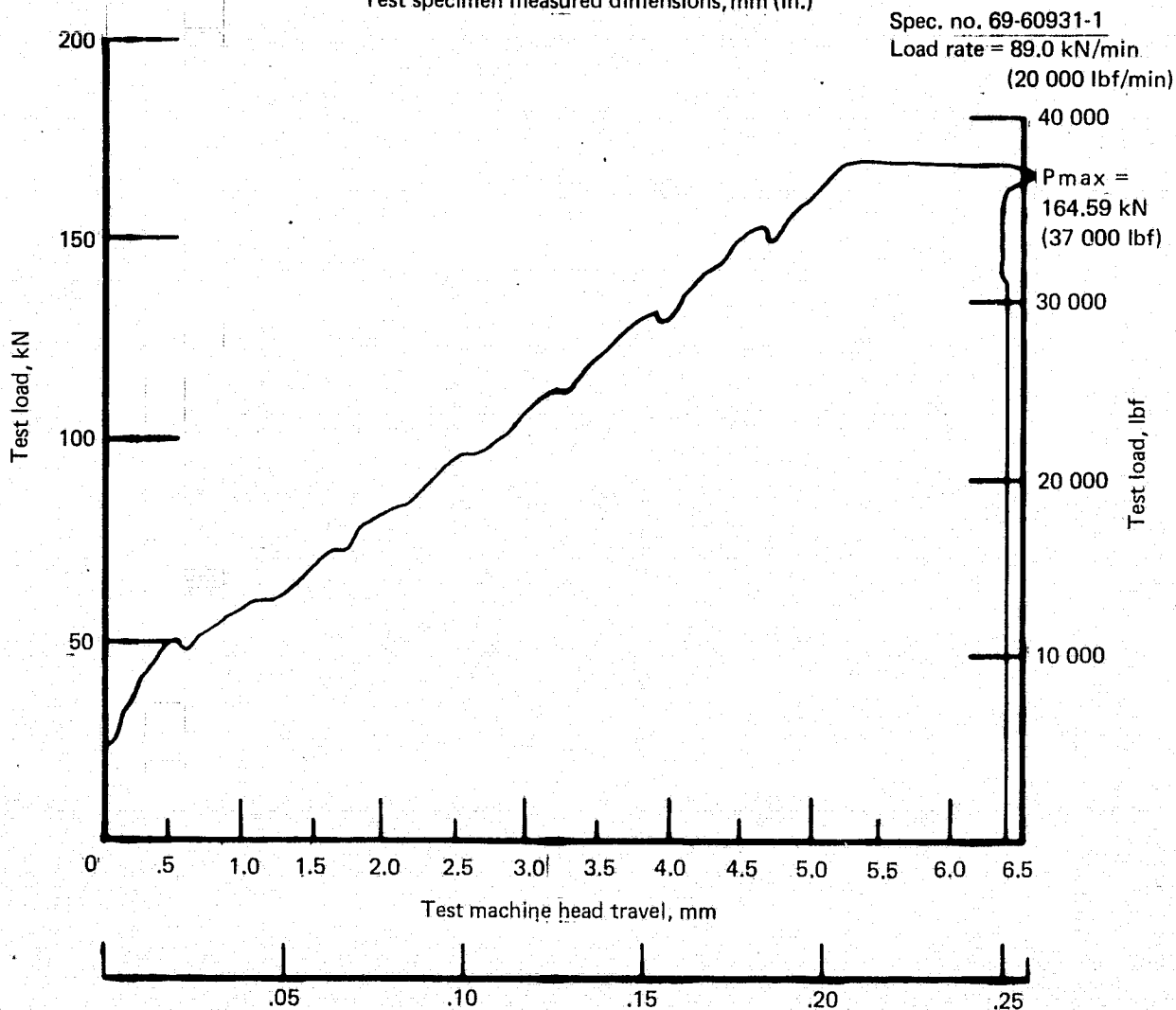
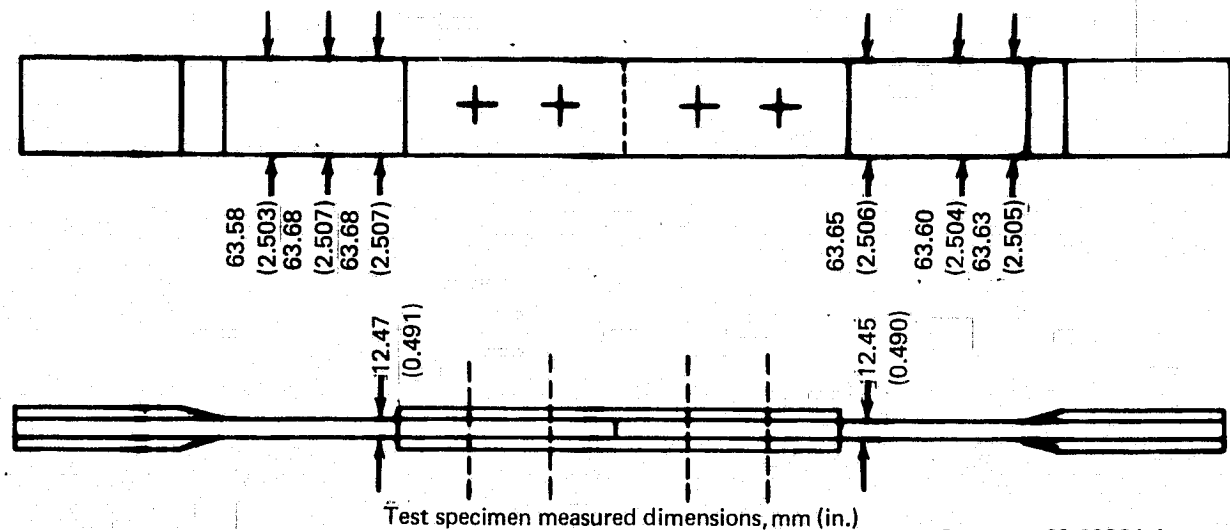


Figure 14.—Load Versus Test Machine Head Travel for the Double Row Concept Specimen 69-60931-1, W/D of 5

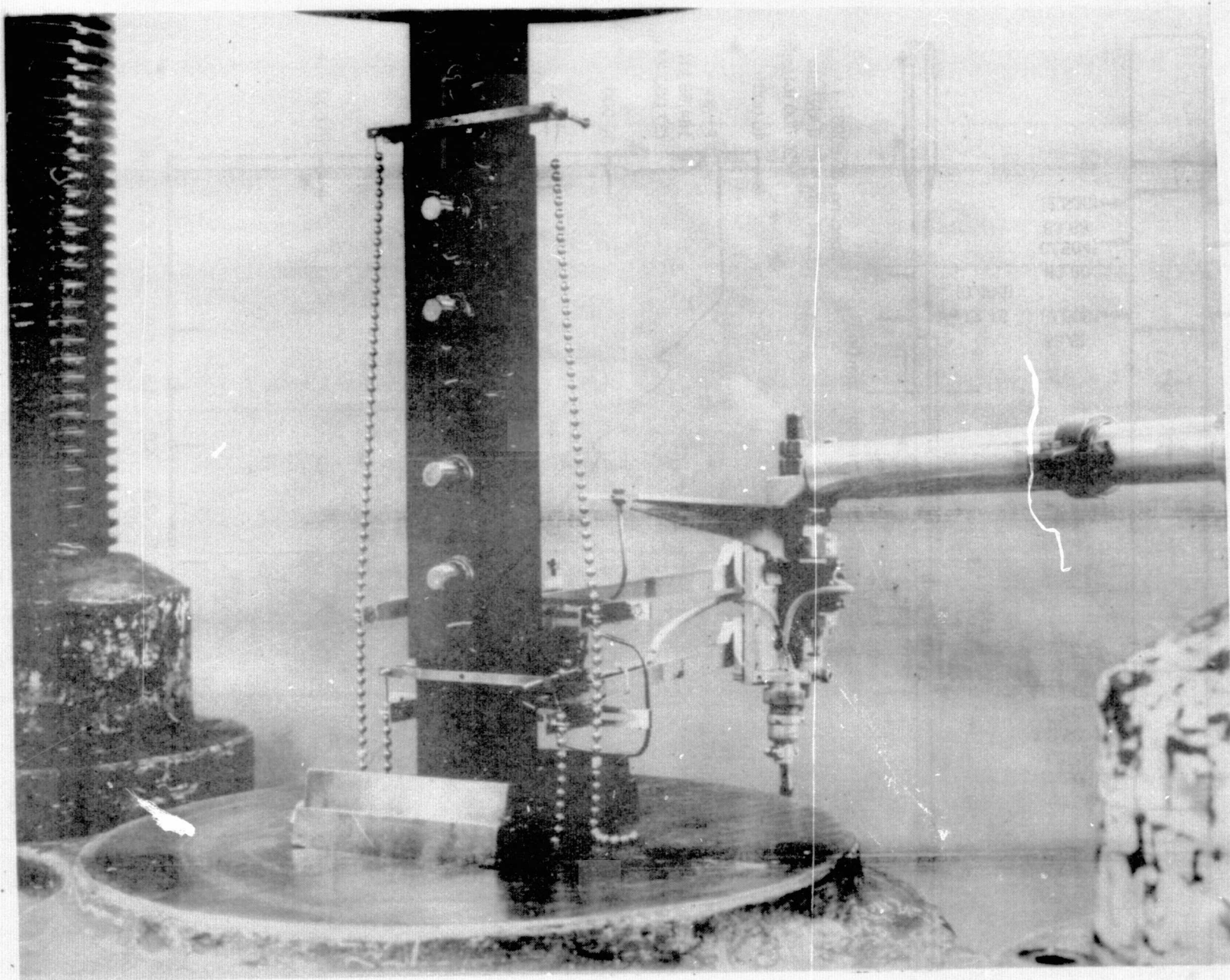


Figure 15.—Test Setup for the 69-60931 Double-Row Joint Specimen

Table 4.—Test Results of the Double Row Joint Concept Specimens

Specimen description	Specimen number	Width, mm (in.)	Thickness, mm (in.)	Gross area, mm ² (in. ²)	Fastener dia, mm (in.)	W/D	Net area, mm ² (in. ²)	Failure load, kN (lbf)	Net area stress, MPa (psi)	Bearing stress, MPa (psi)	Type of failure
Double row W/D = 8.0	69-60933-1	63.58 (2.503)	12.48 (0.491)	793.79 (1.230)	7.94 (5/16)	(8.01)	694.71 (1.077)	162.59 (36 550)	234.09 (33 944)	820.57 (118 983)	Tension/ bearing
	-2	63.58 (2.503)	12.68 (0.499)	806.22 (1.249)	7.94 (5/16)	(8.01)	705.55 (1.094)	166.26 (37 375)	235.69 (34 175)	826.15 (119 792)	Tension/ bearing
	-3	63.60 (2.504)	12.49 (0.492)	794.46 (1.231)	7.94 (5/16)	(8.01)	695.29 (1.078)	164.92 (37 075)	237.25 (34 401)	831.85 (120 618)	Tension/ bearing
Double row joint W/D = 6.67	69-60934-1	63.64 (2.505)	13.25 (0.522)	843.46 (1.307)	9.53 (3/8)	(6.68)	717.22 (1.112)	169.71 (38 150)	236.67 (34 317)	672.30 (97 483)	Tension
	-2	63.64 (2.506)	13.70 (0.539)	871.98 (1.352)	9.53 (3/8)	(6.69)	742.13 (1.150)	168.82 (37 950)	227.53 (32 992)	646.95 (93 808)	Tension
	-3	63.68 (2.507)	13.64 (0.537)	868.39 (1.346)	9.53 (3/8)	(6.68)	739.51 (1.145)	172.60 (38 800)	233.76 (33 896)	664.52 (96 356)	Tension
Double row joint W/D = 5.0	69-60931-1	63.65 (2.506)	12.47 (0.491)	793.83 (1.230)	12.70 (1/2)	(5.01)	635.48 (0.985)	164.60 (37 000)	259.05 (37 563)	519.70 (75 356)	Tension
	-2	63.60 (2.504)	12.65 (0.498)	804.51 (1.247)	12.70 (1/2)	(5.00)	643.87 (0.998)	174.38 (39 200)	270.88 (39 278)	542.86 (78 715)	Tension
	-3	63.60 (2.504)	12.78 (0.503)	812.59 (1.259)	12.70 (1/2)	(5.00)	650.32 (1.008)	169.04 (38 000)	259.98 (37 698)	521.01 (75 547)	Tension

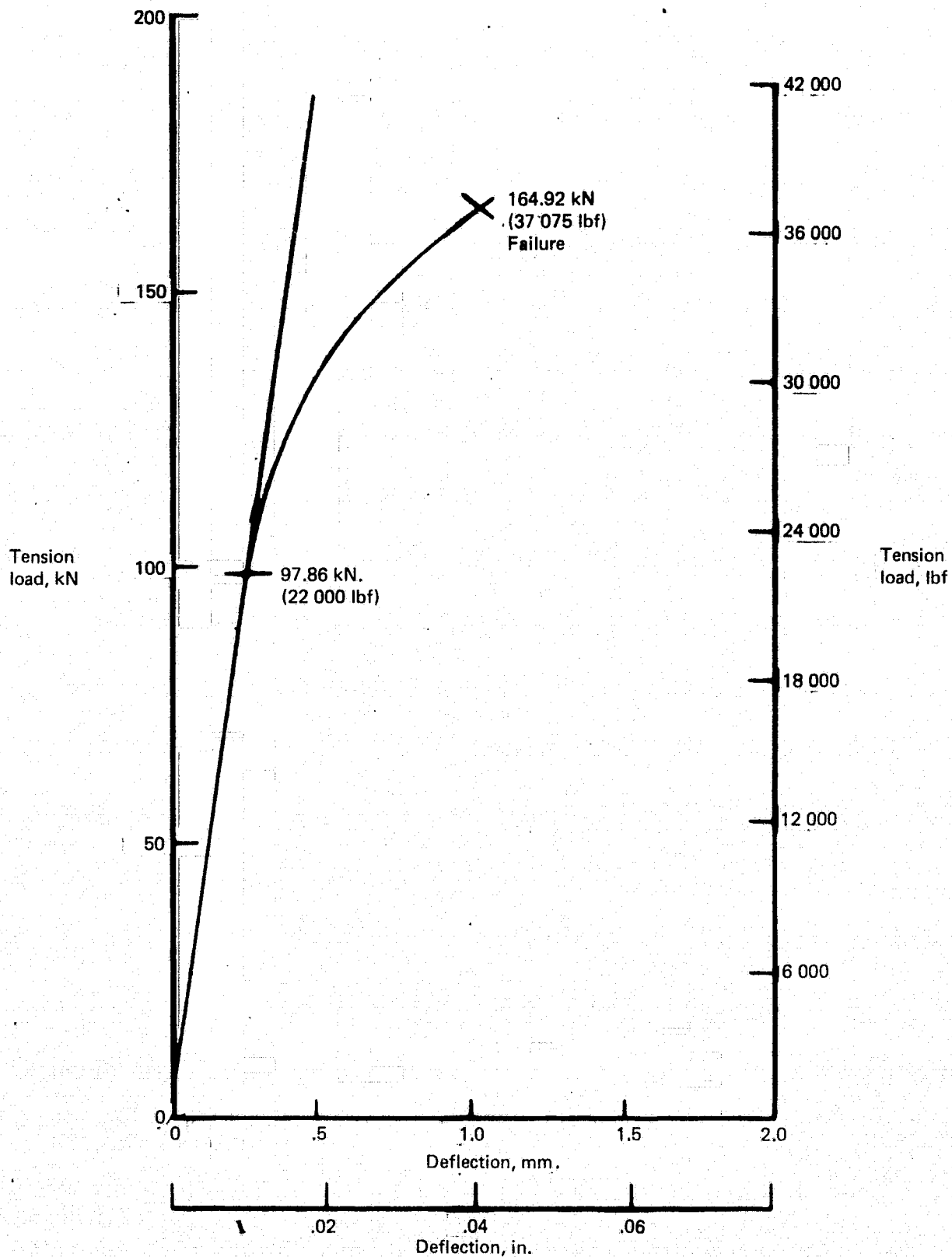
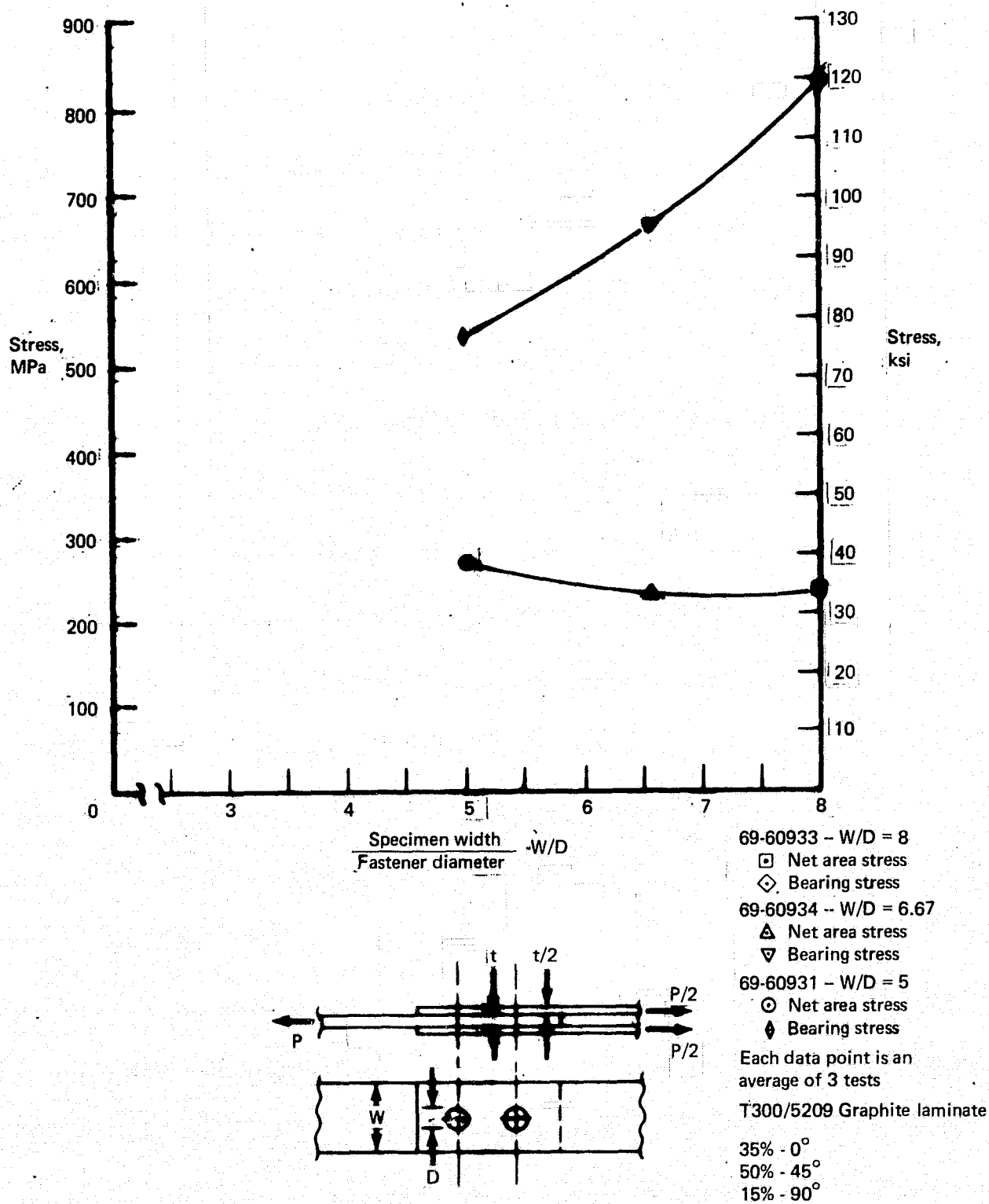


Figure 16.—Typical Load/Deflection Curve for 69-60933 Specimen at $W/D=8$



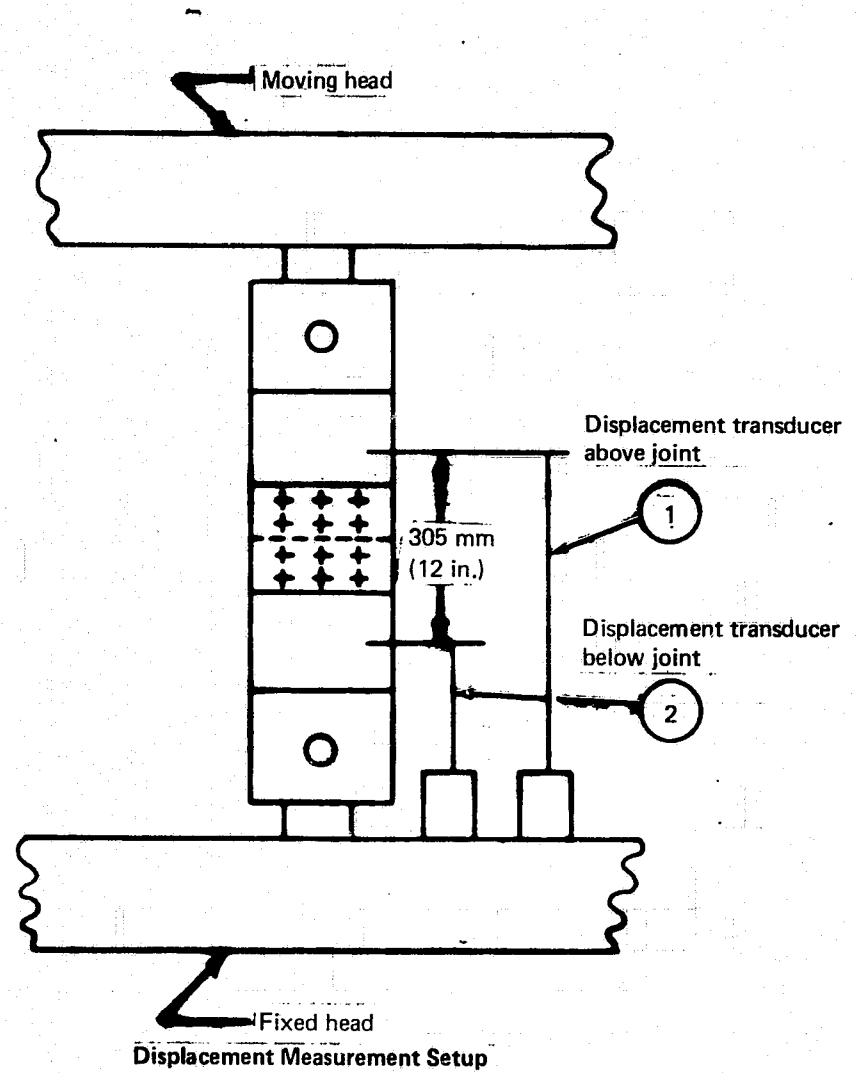
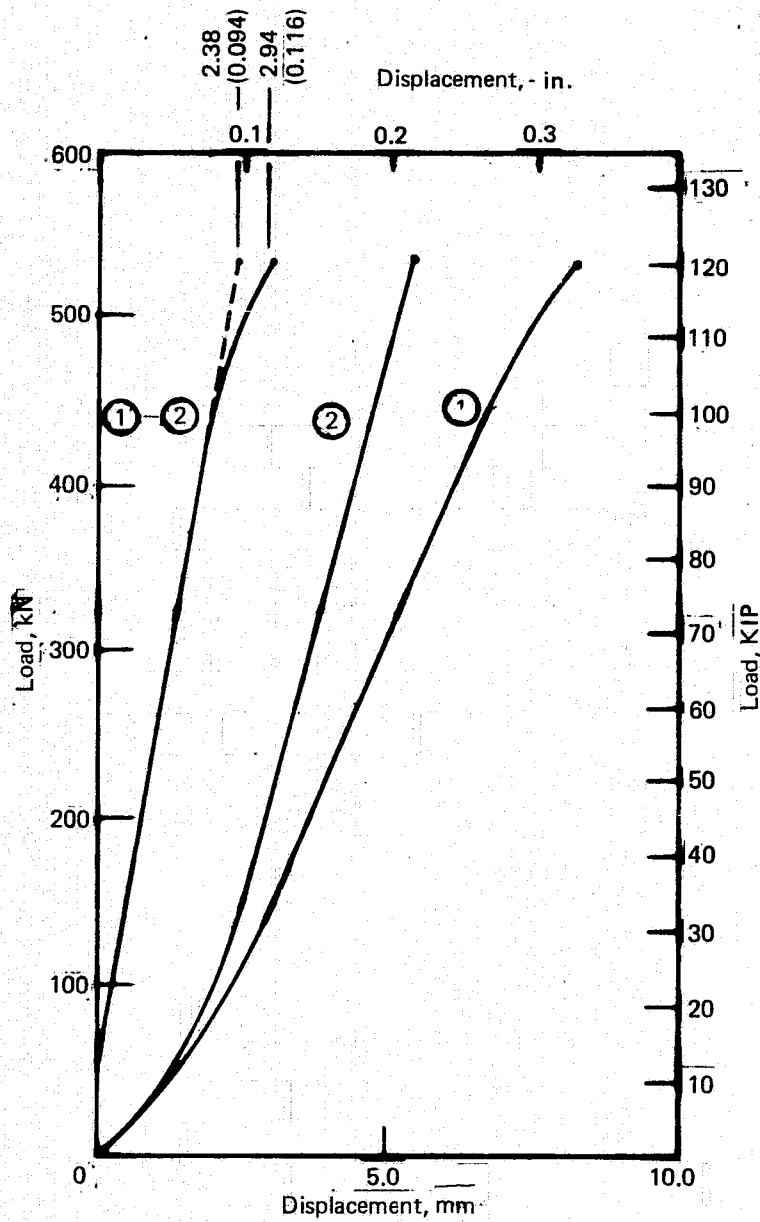


Figure 18.—Plot of Joint Displacement Versus Load for the 69-60930 Wing Skin Splice Specimen

Table 5.—Test Results of the Final Graphite Basic Material Specimens

Specimen Description	Specimen number	Width mm (in.)	Thickness mm (in.)	Area mm ² (in. ²)	Failure Load, kN (lb _f)	Failure Stress, MPa (psi)	Modulus, GPa (psi x 10 ⁶)
Graphite basic material specimen	69-60929-1	50.7898 (1.9996)	9.7180 (0.3826)	493.577 (0.7650)	269.128 (60 500)	545.414 (79 085)	71.241 (10.33)
	-2	50.7593 (1.9984)	9.7358 (0.3833)	494.182 (0.7660)	309.164 (69 500)	625.73 (90 731)	68.345 (9.91)
	-3	50.7517 (1.9981)	9.7358 (0.3833)	494.108 (0.7659)	272.464 (61 250)	551.524 (79 971)	68.345 (9.91)
	-4	50.7898 (1.9996)	9.8273 (0.3869)	499.124 (0.7736)	291.370 (65 500)	583.924 (84 669)	67.103 (9.73)
	-5	44.450 (1.7500)	9.6241 (0.3789)	427.787 (0.6631)	229.092 (51 500)	535.627 (77 666)	67.862 (9.84)

6.0 CONCLUSIONS AND RECOMMENDATIONS

Design values of net area and bearing stresses for a particular graphite laminate were determined by testing a series of mechanical joint specimens. This procedure was shown to be a viable approach since good correlation was obtained between predicted and test values.

Test results have shown an approximate linear relationship between net area and bearing stresses and W/D .

Test results obtained in this program indicate that net area and bearing stresses obtained for a single repeating section can be used for a multiple width repetitive section.

The static test results indicate that the final joint is a viable static load design for a wing skin splice for a 2627-kN/m (15 000-lbf/in.) tension load.

More test programs similar to this program should be conducted to provide a data base to develop and correlate analysis methods for graphite bolted joints.

APPENDIX A

FATIGUE TEST SPECTRUM DATA FOR THE GRAPHITE-EPOXY BOLTED JOINT SPECIMENS

A test spectrum has been established for the lower wing surface side-of-body splice for the 727 airplane. This test spectrum consists of a 2000-flight group with 5 flight types. Occurrences per flight, exceedances per flight, and exceedances per 2000 flights are shown in table 6. This information was taken from references 3 through 6. The 1-g load has been established at 0.275 of the limit load, and the number of flights for one lifetime is defined as 45 000.

Figure 19 illustrates a typical C-type flight, and Boeing recommends that the full 2000 flights be assembled in a random fashion.

Table 6.—Fatigue Spectrum Data

	Flight type	No. of flight type per 2000 flights	Alternating cycle level—fraction of 1-G load ^a								No. of cycles per flight
			1.0	0.85	0.75	0.65	0.55	0.45	0.35	0.25	
Occurrences per flight	A'	1	1	1	2	3	8	27	210	2500	2752
	A	1		1	2	3	8	27	210	2500	2751
	B	18				1	3	9	40	250	303
	C	180						1	4	30	35
	D	1800							1	6	7
Exceedances per flight	A'	1	1	2	4	7	15	42	252	2752	
	A	1		1	3	6	14	41	251	2751	
	B	18				1	4	13	53	303	
	C	180						1	5	35	
	D	1800							1	7	
Exceedances per 2000 flights	A'		1	2	4	7	15	42	252	2752	
	A			1	3	6	14	41	251	2751	
	B					18	72	234	954	5454	
	C							180	900	6300	
	D								1800	12 600	

^a1-G load defined as 0.275 limit load

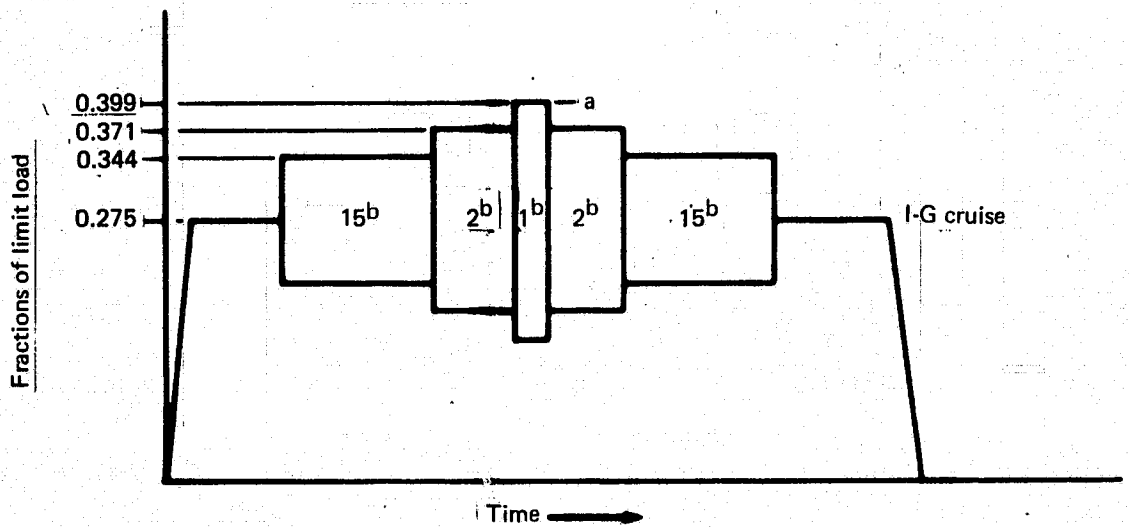


Figure 19.—Example of a C-Type Flight

$$^a(0.275 + 0.45 (^b(0.275))) = 0.399$$

^bnumber of cycles

APPENDIX B DESIGN DRAWINGS

This appendix contains all design drawings that were produced for this program. See figures 20 through 28. SI units for these figures may be obtained by using the following conversion table.

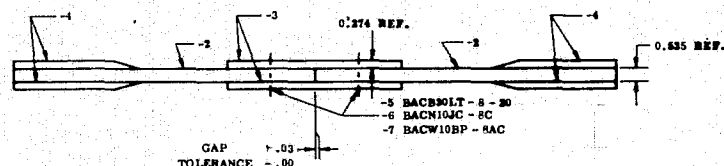
Physical measurement	U.S. customary unit	Conversion factor ^a	SI unit
Length	in.	0.0254	Meter (m)
Torque	in-lbf	0.113	Meter-newton (m-N)
Stress	lbf/in ² (psi)	0.0068948	Mega-pascals (MPa)

^aMultiply the value in U.S. customary units by the conversion factor to obtain the value in SI units.

Prefixes to indicate multiples of units are as follows:

milli (m)	10^{-3}
kilo (k)	10^3
mega (M)	10^6
giga (G)	10^9

DATE	DESCRIPTION	AMOUNT	CHECK NO.	BANK	INITIALS
10/1/78	10/1/78	100.00	100	100	100
10/2/78	10/2/78	100.00	100	100	100
10/3/78	10/3/78	100.00	100	100	100
10/4/78	10/4/78	100.00	100	100	100
10/5/78	10/5/78	100.00	100	100	100
10/6/78	10/6/78	100.00	100	100	100
10/7/78	10/7/78	100.00	100	100	100
10/8/78	10/8/78	100.00	100	100	100
10/9/78	10/9/78	100.00	100	100	100
10/10/78	10/10/78	100.00	100	100	100
10/11/78	10/11/78	100.00	100	100	100
10/12/78	10/12/78	100.00	100	100	100
10/13/78	10/13/78	100.00	100	100	100
10/14/78	10/14/78	100.00	100	100	100
10/15/78	10/15/78	100.00	100	100	100
10/16/78	10/16/78	100.00	100	100	100
10/17/78	10/17/78	100.00	100	100	100
10/18/78	10/18/78	100.00	100	100	100
10/19/78	10/19/78	100.00	100	100	100
10/20/78	10/20/78	100.00	100	100	100
10/21/78	10/21/78	100.00	100	100	100
10/22/78	10/22/78	100.00	100	100	100
10/23/78	10/23/78	100.00	100	100	100
10/24/78	10/24/78	100.00	100	100	100
10/25/78	10/25/78	100.00	100	100	100
10/26/78	10/26/78	100.00	100	100	100
10/27/78	10/27/78	100.00	100	100	100
10/28/78	10/28/78	100.00	100	100	100
10/29/78	10/29/78	100.00	100	100	100
10/30/78	10/30/78	100.00	100	100	100
10/31/78	10/31/78	100.00	100	100	100
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11/2/78	11/2/78	100.00	100	100	100
11/3/78	11/3/78	100.00	100	100	100
11/4/78	11/4/78	100.00	100	100	100
11/5/78	11/5/78	100.00	100	100	100
11/6/78	11/6/78	100.00	100	100	100
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11/11/78	11/11/78	100.00	100	100	100
11/12/78	11/12/78	100.00	100	100	100
11/13/78	11/13/78	100.00	100	100	100
11/14/78	11/14/78	100.00	100	100	100
11/15/78	11/15/78	100.00	100	100	100
11/16/78	11/16/78	100.00	100	100	100
11/17/78	11/17/78	100.00	100	100	100
11/18/78	11/18/78	100.00	100	100	100
11/19/78	11/19/78	100.00	100	100	100
11/20/78	11/20/78	100.00	100	100	100
11/21/78	11/21/78	100.00	100	100	100
11/22/78	11/22/78	100.00	100	100	100
11/23/78	11/23/78	100.00	100	100	100
11/24/78	11/24/78	100.00	100	100	100</



- ▶ ALL LAMINATE WILL BE SUBJECTED TO X-RAY AND ULTRASONIC INSPECTION AFTER TO FINAL ACCEPTANCE
- ▶ BOND - 4 TO - 8 WITH RESIN 5-101 APPROVED
- ▶ INSTALL WASHER UNDER BOLT HEAD AND NUT - PLACE COUNTERBORN WASHER SURFACE AGAINST BOLT HEAD
- ▶ MAXIMUM TORQUE 300 IN. - LBS.
- ▶ NO THREADS ALLOWED IN BEARING - INSTALL IN CLASS 1 HOLE - 0.500^{+0.005}_{-0.000}
- ▶ NARMCO T200/AS99 - 8 HARMING SATIN WEAVE CLOTH - 0.013 IN. PER PLY WITH 0.004 IN. THICK UNIDIRECTIONAL TAPE - SEE SHEET 2 FOR ORIENTATION

TRAINING RECORDS CLERK

Figure 20. —Single-Row Graphite Bolted Joint

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES		FORM, PUNCH, STRAIGHTEN & FIT METAL PARTS PER BAC5300		REVISIONS																																																																																																																																																															
TOLERANCES:		MATERIAL SUBSTITUTION & EQUIVALENTS PER 45-M700		REV	DESCRIPTION	DATE	APPROVED																																																																																																																																																												
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Figure 20.—(Concluded)

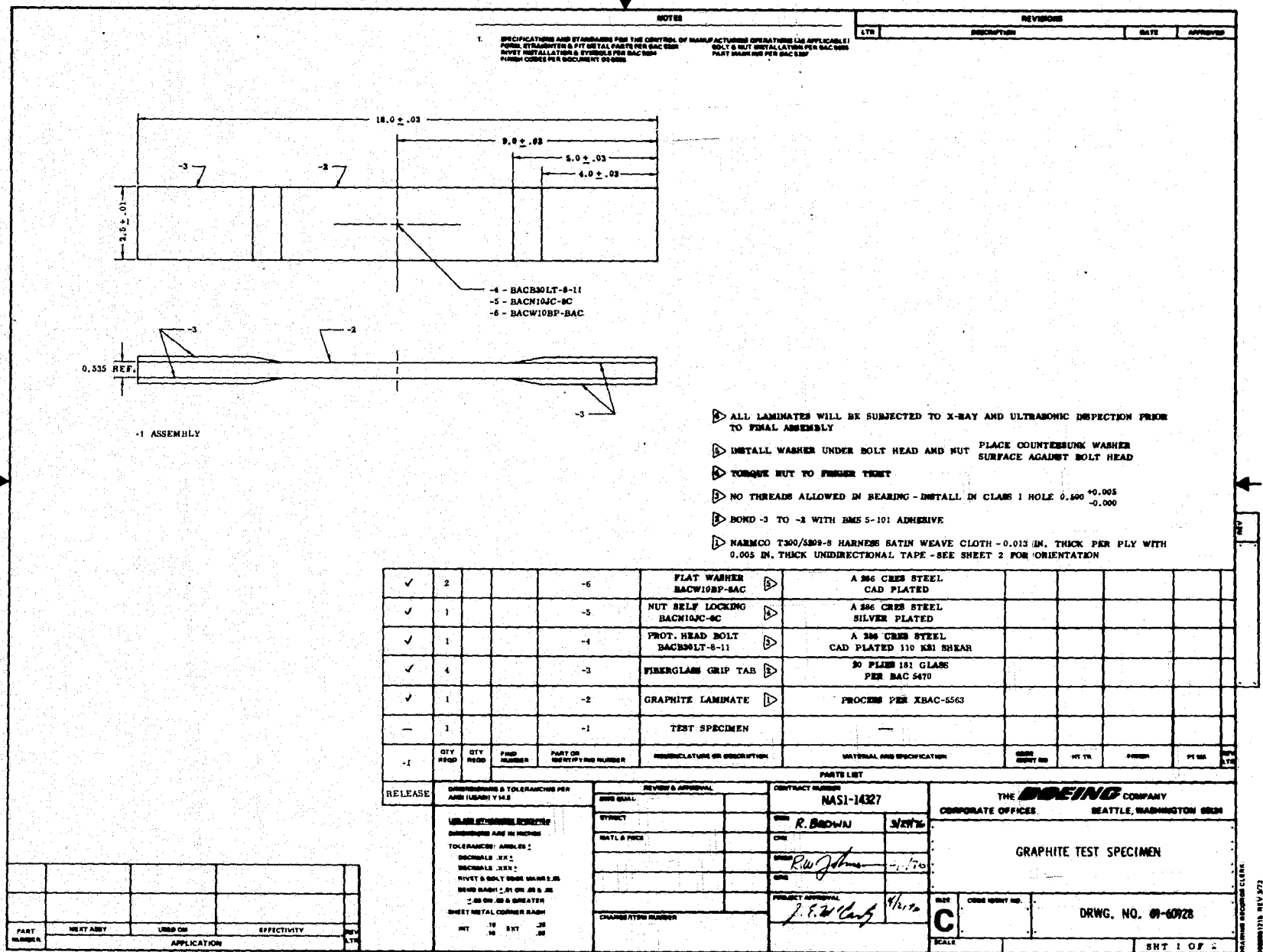


Figure 21.—Graphite Test Specimen

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES: ANGLES $\pm$ DECIMALS $\pm$ RIVET & BOLT EDGE MARGINS $\pm$.05 BEND RADIUS $\pm$.01 ON .03 & .06 $\pm$.03 ON .09 & GREATER SHEET METAL CORNER RADIUS INTERNAL .19 16 EXTERNAL .25 .00		FORM, PUNCH, STRAIGHTEN & FIT METAL PARTS PER BAC5300 MATERIAL SUBSTITUTION & EQUIVALENTS PER 45-88700 BOLT & NUT INSTALLATION PER BAC 5009 PART MARKING PER BAC 5307 SEE BAC D2097 FOR SURFACE ROUGHNESS FOR FINISH CODE SEE DOCUMENT D2-5000 OR D6-5000 DIMENSIONING & TOLERANCING PER USAS 1Y14.5		REVISIONS <table border="1"> <thead> <tr> <th>REV</th> <th>DESCRIPTION</th> <th>DATE</th> <th>APPROVED</th> </tr> </thead> <tbody> <tr> <td> </td> <td> </td> <td> </td> <td> </td> </tr> </tbody> </table>		REV	DESCRIPTION	DATE	APPROVED																																																																													
REV	DESCRIPTION	DATE	APPROVED																																																																																			
FASTENER SYMBOL CODE INSTL. STD. PER BAC 5004; FLUID TIGHT. PER BAC 5047 BASIC CODE ENCLOSED = FLUID TIGHT OPEN = STANDARD DIMPLE/CSK INFO D = DIMPLE 2 = NO SH DIMPLE C = CSK INSTRUCTURE 2 LINES: TOP = MFD HD. BOTTOM = DRIVEN HD NOTE: PROTRUDING HD RIVETS DRIVEN FLUSH D/C INFO (2 LINES) APPLIES TO DRIVEN HD ONLY 1. HOLE LOCATION FOR X/32 DIAMETER RIVET 2. HOLE LOCATION FOR X/32 DIAMETER BOLT		LAMINATE ORIENTATION --2 <table border="1"> <thead> <tr> <th>LAYER</th> <th>ORIENTATION</th> <th>MATERIAL</th> </tr> </thead> <tbody> <tr><td>1</td><td>0/90</td><td>CLOTH</td></tr> <tr><td>2</td><td>+45</td><td>"</td></tr> <tr><td>3</td><td>0</td><td>TAPE</td></tr> <tr><td>4</td><td>+45</td><td>CLOTH</td></tr> <tr><td>5</td><td>0</td><td>TAPE</td></tr> <tr><td>6</td><td>0/90</td><td>CLOTH</td></tr> <tr><td>7</td><td>+45</td><td>"</td></tr> <tr><td>8</td><td>0/90</td><td>"</td></tr> <tr><td>9</td><td>+45</td><td>"</td></tr> <tr><td>10</td><td>0</td><td>TAPE</td></tr> <tr><td>11</td><td>+45</td><td>CLOTH</td></tr> <tr><td>12</td><td>0</td><td>TAPE</td></tr> <tr><td>13</td><td>0/90</td><td>CLOTH</td></tr> <tr><td>14</td><td>+45</td><td>"</td></tr> <tr><td>15</td><td>0/90</td><td>"</td></tr> <tr><td>16</td><td>+45</td><td>"</td></tr> <tr><td>17</td><td>0</td><td>TAPE</td></tr> <tr><td>18</td><td>+45</td><td>CLOTH</td></tr> <tr><td>19</td><td>0</td><td>TAPE</td></tr> <tr><td>20</td><td>0/90</td><td>CLOTH</td></tr> <tr><td>21</td><td>+45</td><td>"</td></tr> <tr><td>22</td><td>+45</td><td>"</td></tr> <tr><td>23</td><td>0</td><td>TAPE</td></tr> <tr><td>24</td><td>0/90</td><td>CLOTH</td></tr> <tr><td>25</td><td>0</td><td>TAPE</td></tr> <tr><td>26</td><td>0/90</td><td>CLOTH</td></tr> </tbody> </table> 25 LAYERS SYM. LAYUP OF LAMINATE		LAYER	ORIENTATION	MATERIAL	1	0/90	CLOTH	2	+45	"	3	0	TAPE	4	+45	CLOTH	5	0	TAPE	6	0/90	CLOTH	7	+45	"	8	0/90	"	9	+45	"	10	0	TAPE	11	+45	CLOTH	12	0	TAPE	13	0/90	CLOTH	14	+45	"	15	0/90	"	16	+45	"	17	0	TAPE	18	+45	CLOTH	19	0	TAPE	20	0/90	CLOTH	21	+45	"	22	+45	"	23	0	TAPE	24	0/90	CLOTH	25	0	TAPE	26	0/90	CLOTH	SEE SHEET PL FOR LIST OF MATERIAL, NOTES AND USAGE THE BOEING COMPANY TITLE: GRAPHITE TEST SPECIMEN NAS 1-14327 NUMBER: 69-60928 PAGE: OF SHEET: 2 OF 2 REV:	
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Figure 21.—(Concluded)

NOTES				REVISIONS			
1. SPECIFICATIONS AND STANDARDS FOR THE CONTROL OF MANUFACTURING OPERATIONS (AS APPLICABLE): FORM STRAIGHTEN & FIT METAL PARTS PER BAC 589 BOLT & NUT INSTALLATION PER BAC 589 RIVET INSTALLATION & SYMBOLS PER BAC 589 PART MARKING PER BAC 589 FINISH CODES PER DOCUMENT D2-8888				LTR	DESCRIPTION	DATE	APPROVED
-1 ASSEMBLY							
▶ ALL LAMINATES WILL BE SUBJECTED TO X-RAY AND ULTRASONIC INSPECTION PRIOR TO FINAL ASSEMBLY ▶ BOND -3 TO -2 WITH EHS 5-101 ADP-SIVE ▶ NARMCO T300/5009-8 HARNESS SAT4 WEAVE CLOTH - 0.012 IN. THICK PER PLY WITH 0.005 IN. THICK UNIDIRECTIONAL TAPE - SEE SHEET 3 FOR ORIENTATION							
✓	4		-3	FIBERGLASS GRIP TAB	▶ 30 PLYS 181 GLASS PER BAC 5470		
✓	1		-2	GRAPHITE LAMINATE	▶ PROCESS PER XBAC - 5063		
—	1		-1	TEST SPECIMEN	—		
-1	QTY REQD	QTY PROD	FINI NUMBER	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	MAT'L AND SPECIFICATION	CHG. SHEET NO.
PART LIST							
RELEASE				REVIEW & APPROVAL			
DESIGNING & TOLERANCING PER AMS (UNLESS NOTED)				DESIGNER		CHECKER	
DIMENSIONS ARE IN INCHES TOLERANCES: ANGLES: 1° DECIMALS: .005 RIVET & BOLT EDGE RADIUS: .015 IN. MIN. & .015 IN. MAX. IN. & GREATER SHEET METAL CORNER RADIUS: .015 IN. MIN. & .015 IN. MAX.				DRAWN		DATE	
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INT 2 EXT 20				CONTRACT #		DATE	
INT 1 EXT 20				CONTRACT #		DATE	
INT 0 EXT 20				CONTRACT #		DATE	
INT -1 EXT 20				CONTRACT #		DATE	
INT -2 EXT 20				CONTRACT #		DATE	
INT -3 EXT 20				CONTRACT #		DATE	
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UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES		FORM PUNCH STRAIGHTEN & FIT METAL PARTS PER BACS300		REVISIONS	
TOLERANCES:		MATERIAL SUBSTITUTION & EQUIVALENTS PER 65-88700		REV	DESCRIPTION
ANGLES ± DECIMALS ±		BOLT & NUT INSTALLATION PER BAC 5009		DATE	APPROVED
RIVET & BOLT EDGE MARGINS ± .05		PART MARKING PER BAC 5307			
BEND RADI:		SEE BAC D2097 FOR SURFACE ROUGHNESS			
± .01 ON .03 & .06		FOR FINISH CODE SEE DOCUMENT D2 5000			
± .03 ON .09 & GREATER		DIMENSIONING & TOLERANCING PER USAS IY14 5			
SHEET METAL CORNER RADII					
INTERNAL 16 19 16					
EXTERNAL 22 25 00					

FASTENER SYMBOL CODE

INSTL STD. PER BAC 5004. FLUID TIGHT PER BAC 5047

BASIC CODE

ENCLOSED: FLUID TIGHT
OPEN: STANDARD

DIMPLE / CSK INFO

D: DIMPLE
2: NO. SH DIMPLED
C: CSK INSTRUCTURE
2 LINES TOP: MFD HD. BOTTOM: DRIVEN HD.

NOTE: PROTRUDING HD RIVETS DRIVEN FLUSH
D/C INFO (2 LINES) APPLIES TO DRIVEN HD ONLY

—X— HOLE LOCATION FOR X/32 DIAMETER RIVET

—BX— HOLE LOCATION FOR X/32 DIAMETER BOLT

LAMINATE ORIENTATION - 2

LAYER	1	0/90	CLOTH
	2	+45	"
	3	0	TAPE
	4	+45	CLOTH
	5	0	TAPE
	6	0/90	CLOTH
	7	+45	"
	8	0	TAPE
	9	+45	CLOTH
	10	0	TAPE
	11	0/90	CLOTH
	12	+45	"
	13	0	TAPE
	14	+45	CLOTH
	15	0	TAPE
	16	+45	CLOTH
	17	0	TAPE
	18	0/90	CLOTH
	19	0	TAPE

↓ 19 LAYERS SYM. LAYUP

OF LAMINATE

DRAWN R. BROWN 3/29/76	GROUP ORG	SEE SHEET PL FOR LIST OF MATERIAL, NOTES AND USAGE
CHECKED	ITEM	
ENGR R. W. J. 4/1/76	CHG NO	THE BOEING COMPANY
STRESS	MODEL	TITLE GRAPHITE TEST SPECIMEN NAS 1-14327
GROUP	SECT	
PROJECT M. CARTY 4/2/76	SCALE	NUMBER 69-60929

PAGE	SHEET	REV
OF	2 OF 2	

DRAWING RECORDS CLERK

Figure 22.—(Concluded)

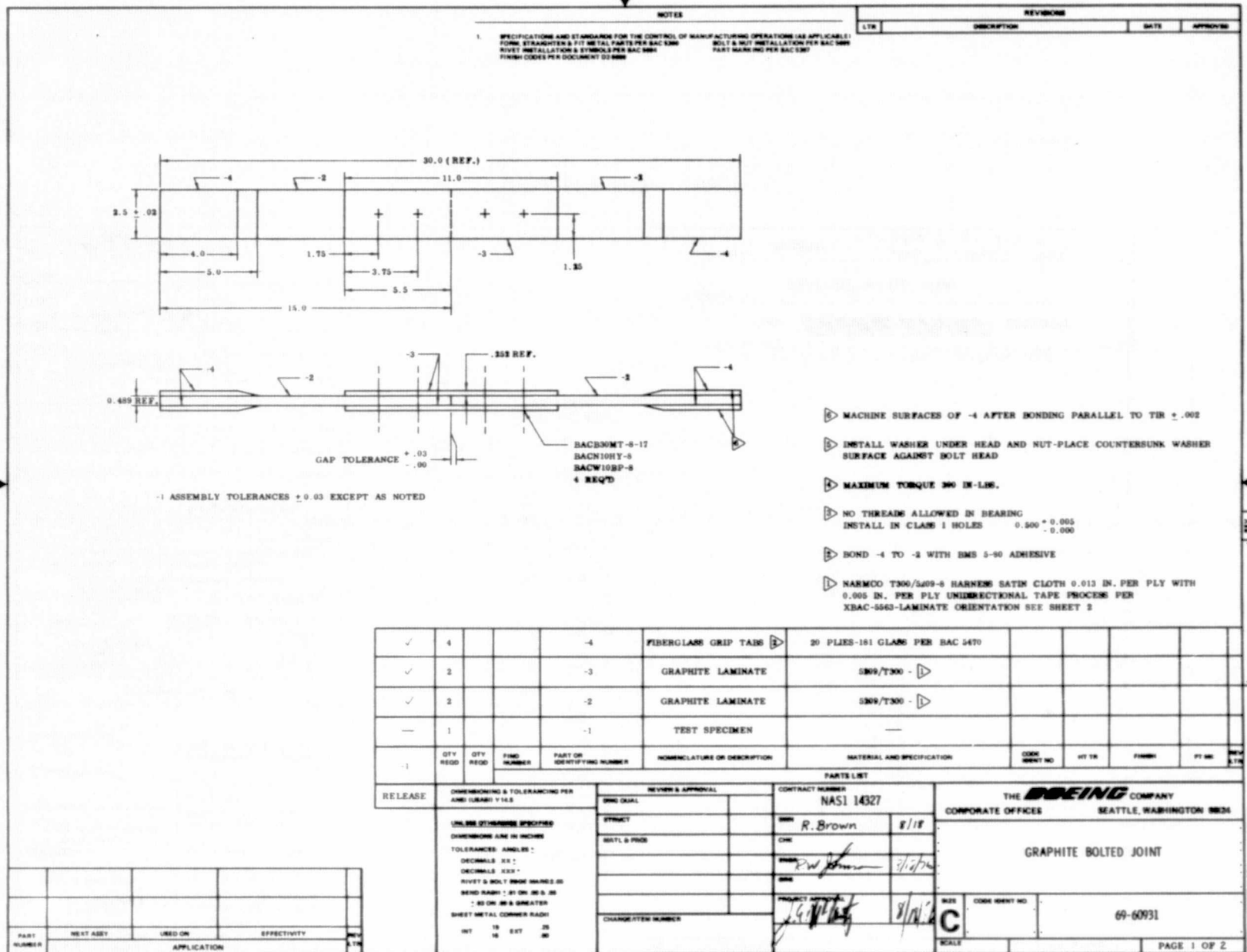


Figure 23.—Graphite Bolted Joint

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ANGLES $\pm$ DECIMALS $\pm$ RIVET & BOLT EDGE MARGINS $\pm$.05 BEND RADII: $\pm$.01 ON .03 & .06 $\pm$.03 ON .09 & GREATER SHEET METAL CORNER RADII INTERNAL 16 16 EXTERNAL 22 00	FORM PUNCH, STRAIGHTEN & FIT METAL PARTS PER BAC5300 MATERIAL SUBSTITUTION & EQUIVALENTS PER 65-88700 BOLT & NUT INSTALLATION PER BAC 5009 PART MARKING PER BAC 5307 SEE BAC D2097 FOR SURFACE ROUGHNESS FOR FINISH CODE SEE DOCUMENT D2-5000 OR D6-5000 DIMENSIONING & TOLERANCING PER USAS 1Y14.5	<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th colspan="2" style="text-align: left;">LAMINATE - 2</th> <th colspan="2" style="text-align: left;">LAMINATE - 3</th> </tr> </thead> <tbody> <tr><td>LAYER 1</td><td>0/90 - C</td><td>LAYER 1</td><td>0/90 - C</td></tr> <tr><td>2</td><td>$\pm$ 45 - C</td><td>2</td><td>$\pm$ 45 - C</td></tr> <tr><td>3</td><td>0 - T</td><td>3</td><td>0 - T</td></tr> <tr><td>4</td><td>$\pm$ 45 - C</td><td>4</td><td>$\pm$ 45 - C</td></tr> <tr><td>5</td><td>$\pm$ 45 - C</td><td>5</td><td>0 - T</td></tr> <tr><td>6</td><td>0 - T</td><td>6</td><td>0/90 - C</td></tr> <tr><td>7</td><td>0/90 - C</td><td>7</td><td>$\pm$ 45 - C</td></tr> <tr><td>8</td><td>0/90 - C</td><td>8</td><td>0 - T</td></tr> <tr><td>9</td><td>$\pm$ 45 - C</td><td>9</td><td>$\pm$ 45 - C</td></tr> <tr><td>10</td><td>0 - T</td><td>10</td><td>0 - T</td></tr> <tr><td>11</td><td>0 - T</td><td>11</td><td>0/90 - C</td></tr> <tr><td>12</td><td>$\pm$ 45 - C</td><td>12</td><td>$\pm$ 45 - C</td></tr> <tr><td>13</td><td>0 - T</td><td></td><td></td></tr> <tr><td>14</td><td>0/90 - C</td><td></td><td></td></tr> <tr><td>15</td><td>0/90 - C</td><td></td><td></td></tr> <tr><td>16</td><td>$\pm$ 45 - C</td><td></td><td></td></tr> <tr><td>17</td><td>0 - T</td><td></td><td></td></tr> <tr><td>18</td><td>$\pm$ 45 - C</td><td></td><td></td></tr> <tr><td>19</td><td>0 - T</td><td></td><td></td></tr> <tr><td>20</td><td>$\pm$ 45 - C</td><td></td><td></td></tr> <tr><td>21</td><td>$\pm$ 45 - C</td><td></td><td></td></tr> <tr><td>22</td><td>0 - T</td><td></td><td></td></tr> <tr><td>23</td><td>0/90 - C</td><td></td><td></td></tr> <tr><td></td><td>0 - T</td><td></td><td></td></tr> </tbody> </table> ↓ 24 PLYS SYM. LAYUP	LAMINATE - 2		LAMINATE - 3		LAYER 1	0/90 - C	LAYER 1	0/90 - C	2	$\pm$ 45 - C	2	$\pm$ 45 - C	3	0 - T	3	0 - T	4	$\pm$ 45 - C	4	$\pm$ 45 - C	5	$\pm$ 45 - C	5	0 - T	6	0 - T	6	0/90 - C	7	0/90 - C	7	$\pm$ 45 - C	8	0/90 - C	8	0 - T	9	$\pm$ 45 - C	9	$\pm$ 45 - C	10	0 - T	10	0 - T	11	0 - T	11	0/90 - C	12	$\pm$ 45 - C	12	$\pm$ 45 - C	13	0 - T			14	0/90 - C			15	0/90 - C			16	$\pm$ 45 - C			17	0 - T			18	$\pm$ 45 - C			19	0 - T			20	$\pm$ 45 - C			21	$\pm$ 45 - C			22	0 - T			23	0/90 - C				0 - T		
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FASTENER SYMBOL CODE	
INSTL. STD. PER BAC 5004: FLUID TIGHT PER BAC 5047 BASIC CODE ENCLOSED: FLUID TIGHT OPEN: STANDARD DIMPLE / CSK INFO D=DIMPLE 2=NO. SH DIMPLED C=CSK INSTRUCTURE 2 LINES TOP=MFD HD. BOTTOM=DRIVEN HD NOTE: PROTRUDING HD RIVETS DRIVEN FLUSH D/C INFO (2 LINES) APPLIES TO DRIVEN HD ONLY	DIA DASH NO. MFD HEAD LOC N=NEAR SIDE F=FAIR SIDE SPOT WELD OPT LENGTH DASH NO.
—X— HOLE LOCATION FOR X/32 DIAMETER RIVET —X— HOLE LOCATION FOR X/32 DIAMETER BOLT	

DRAWN <i>R. Brown 8/18</i> CHECKED <i>[Signature]</i> ENGR <i>[Signature]</i> STRESS <i>[Signature]</i> GROUP <i>[Signature]</i> PROJ <i>[Signature]</i>	GROUP ORG ITEM CHG NO MODEL SECT SCALE
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SEE SHEET PL FOR LIST OF MATERIAL, NOTES AND USAGE			
THE BOEING COMPANY			
TITLE GRAPHITE BOLTED JOINT			
NUMBER 69-60931	PAGE 2 OF 2	SHEET OF	REV

Figure 23.—(Concluded)

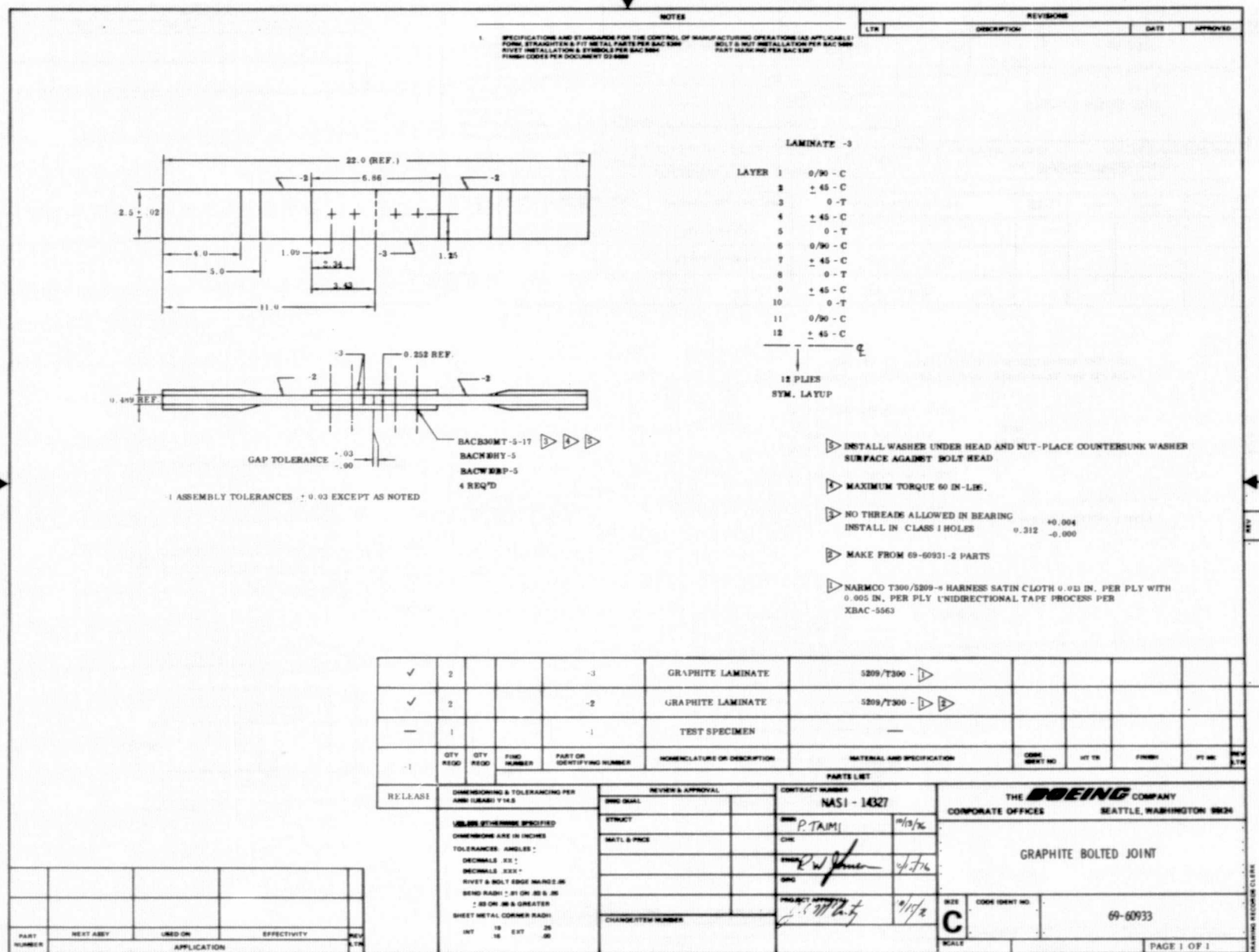


Figure 24.—Graphite Bolted Joint

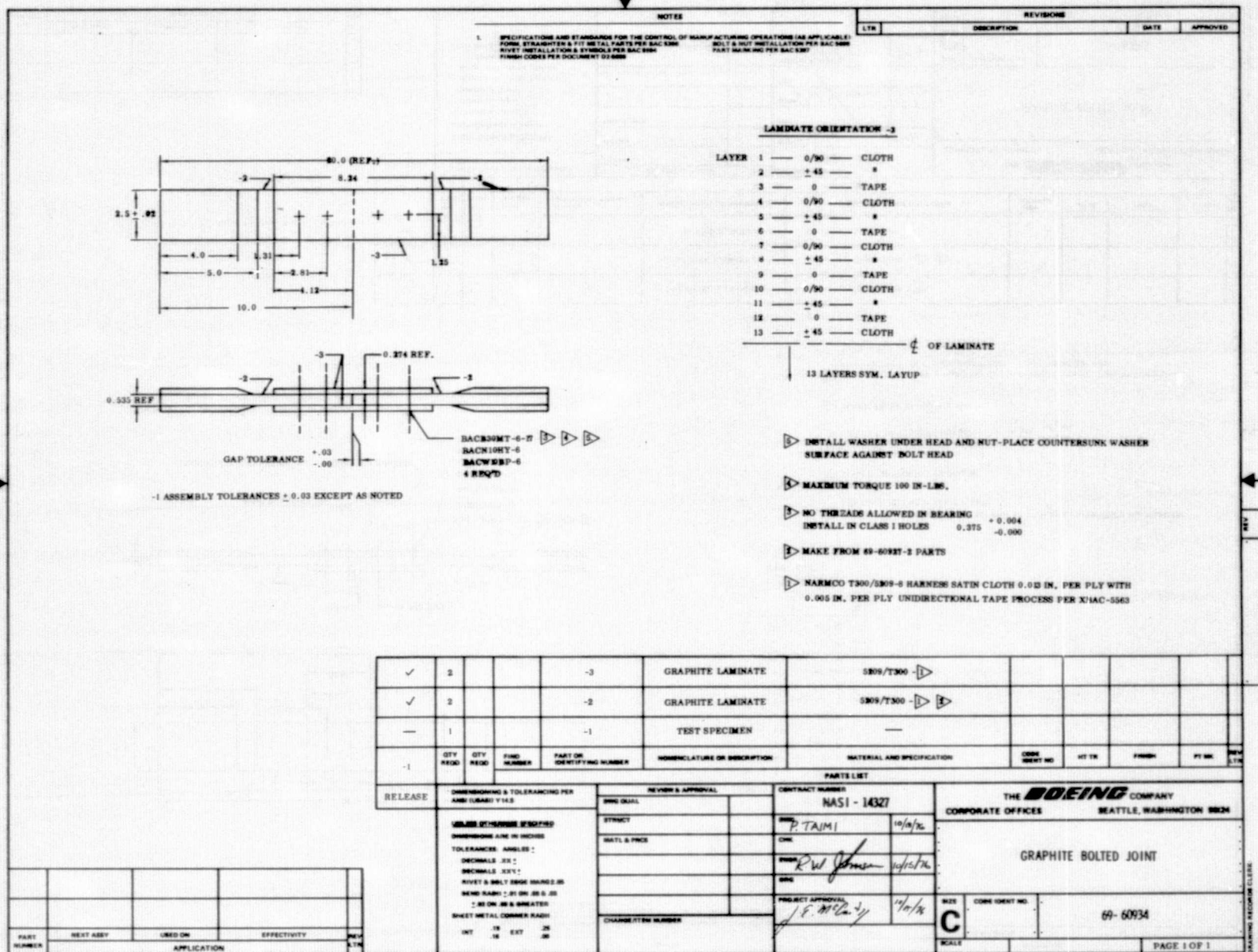


Figure 25.—Graphite Bolted Joint

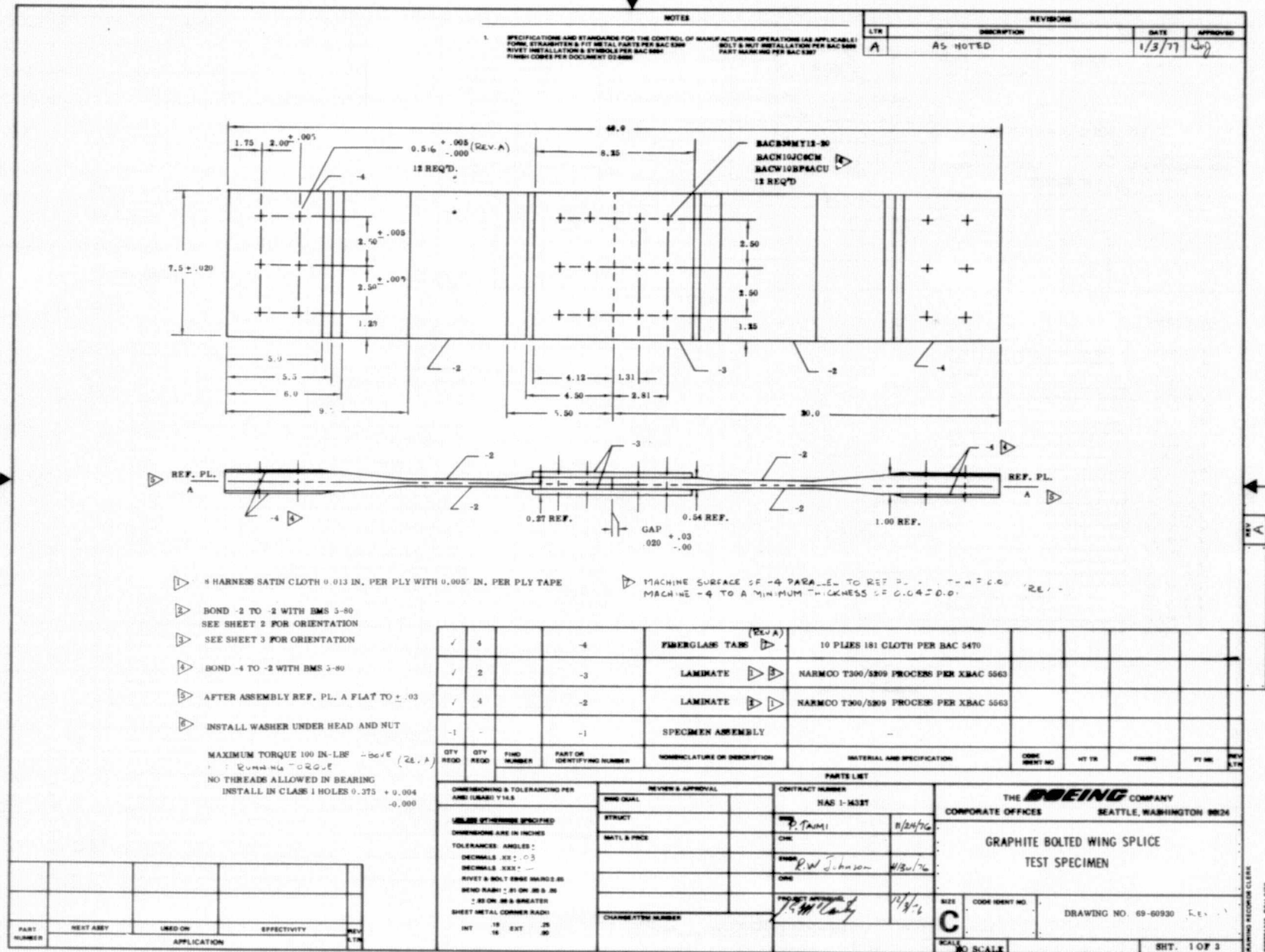


Figure 26.—Graphite Bolted Wing Splice Test Specimen

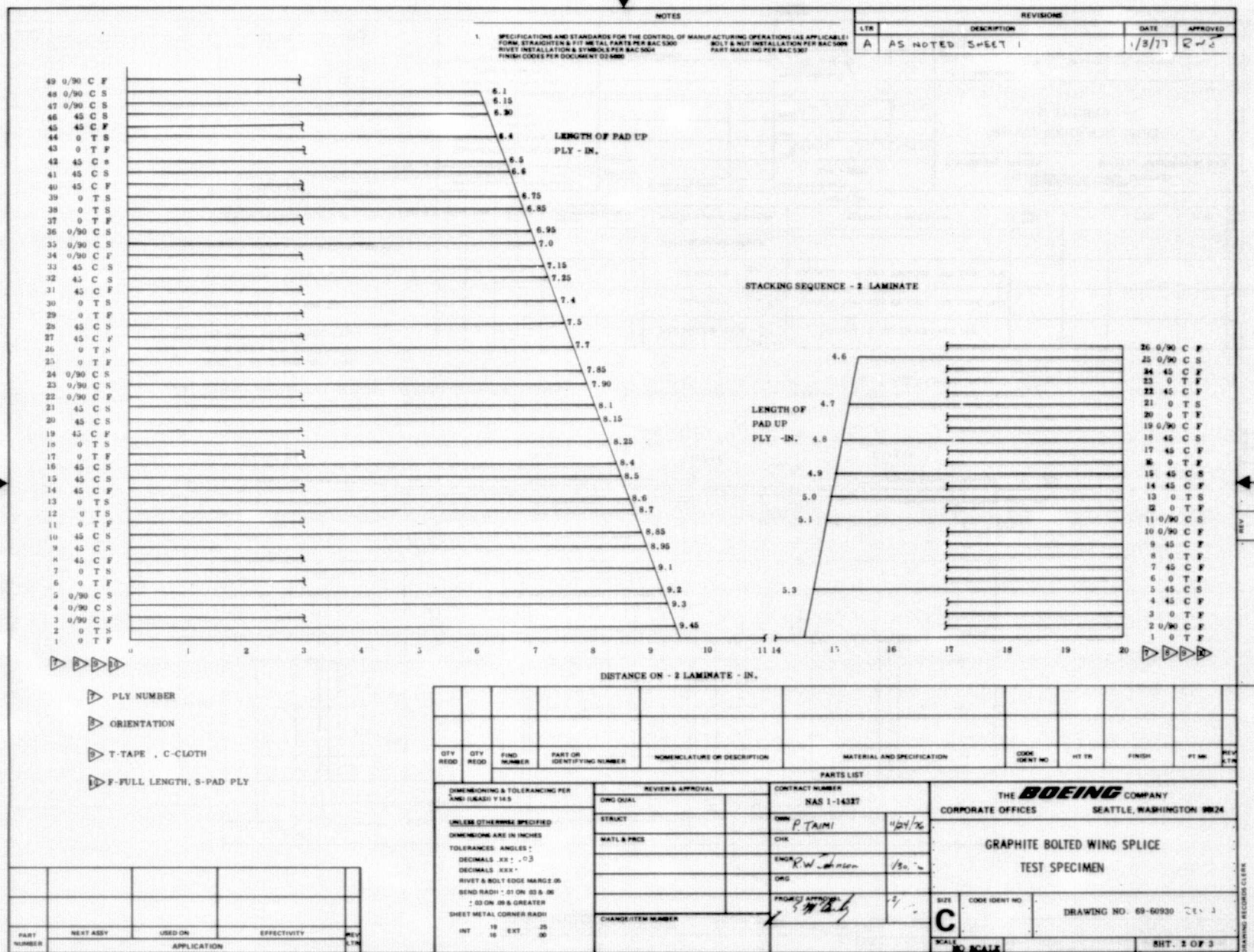


Figure 26.—(Continued)

APPLICATION				PART NUMBER	REV LIT	REVISION		
NEXT ASSY	USED ON	SEC NO	SERIAL NUMBER			SYM	DESCRIPTION	DATE
						A AS NOTED SHEET 1	1/3/77	RWJ

LAMINATE ORIENTATION - 3

LAYER

1	0/90	CLOTH
2	0	TAPE
3	+45	CLOTH
4	+45	"
5	0/90	"
6	0	TAPE
7	+45	CLOTH
8	0	TAPE
9	0/90	CLOTH
10	+45	"
11	0	TAPE
12	+45	CLOTH
13	0	TAPE

↓ 13 LAYERS OF SYMMETRIC LAYUP

OF LAMINATE

PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	MATERIAL AND SPECIFICATION	HT-TR	FINISH	PT-MK	REV LIT

LIST OF MATERIAL			
DIMENSIONING & TOLERANCING PER USAS Y14.5 FORM, PUNCH, STRAIGHTEN & FIT METAL PARTS PER BACS300 MATERIAL SUBSTITUTION & EQUIVALENTS PER BACS505 SST MATERIALS SUBSTITUTIONS & MANUFACTURING PROCESSES PER D6-19736 BOLT & NUT INSTALLATION PER BACS009 PART MARKING PER BACS307 RIVET INSTL & SYM PER BACS004 SEE BACD 20977 FOR SURFACE ROUGHNESS FOR FINISH CODES, SEE DOCUMENT D2-5000 R/FOR D6-5000	UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES: ANGLES ± .1 RIVET & BOLT EDGE MARGINS ± .05 SHEET METAL CORNER RADI: INTERNAL .16 .25 .50 EXTERNAL .22 .25 .50 BEND RADI: ± .01 ON .03 & .06 ± .03 ON .09 & GREATER	DRAWN: P. TAJM/ CHECKED: STRESS: ENG: R. W. D. / GROUP: PROJ:	THE BOEING COMPANY COMMERCIAL AIRPLANE GROUP RENTON, WASH. GRAPHITE BOLTED WING SPLICE TEST SPECIMEN CONTRACT NAS 1-14327 DRAWING NO. 69-00930 SIZE B CODE IDENT NO. 8205 SCALE NO SCALE SH 3 OF 3

Figure 26.—(Concluded)

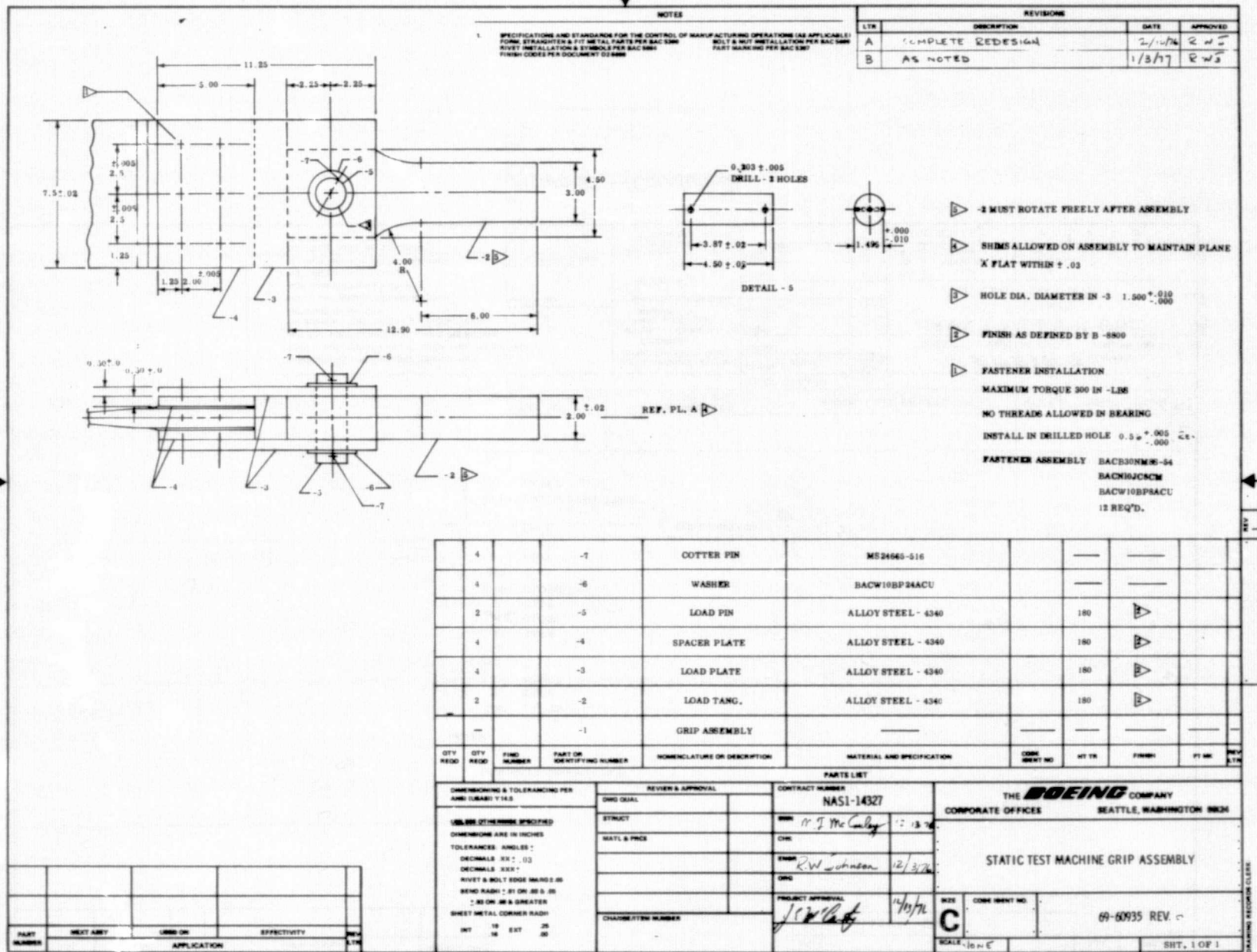


Figure 27.—Static Test Machine Grip Assembly

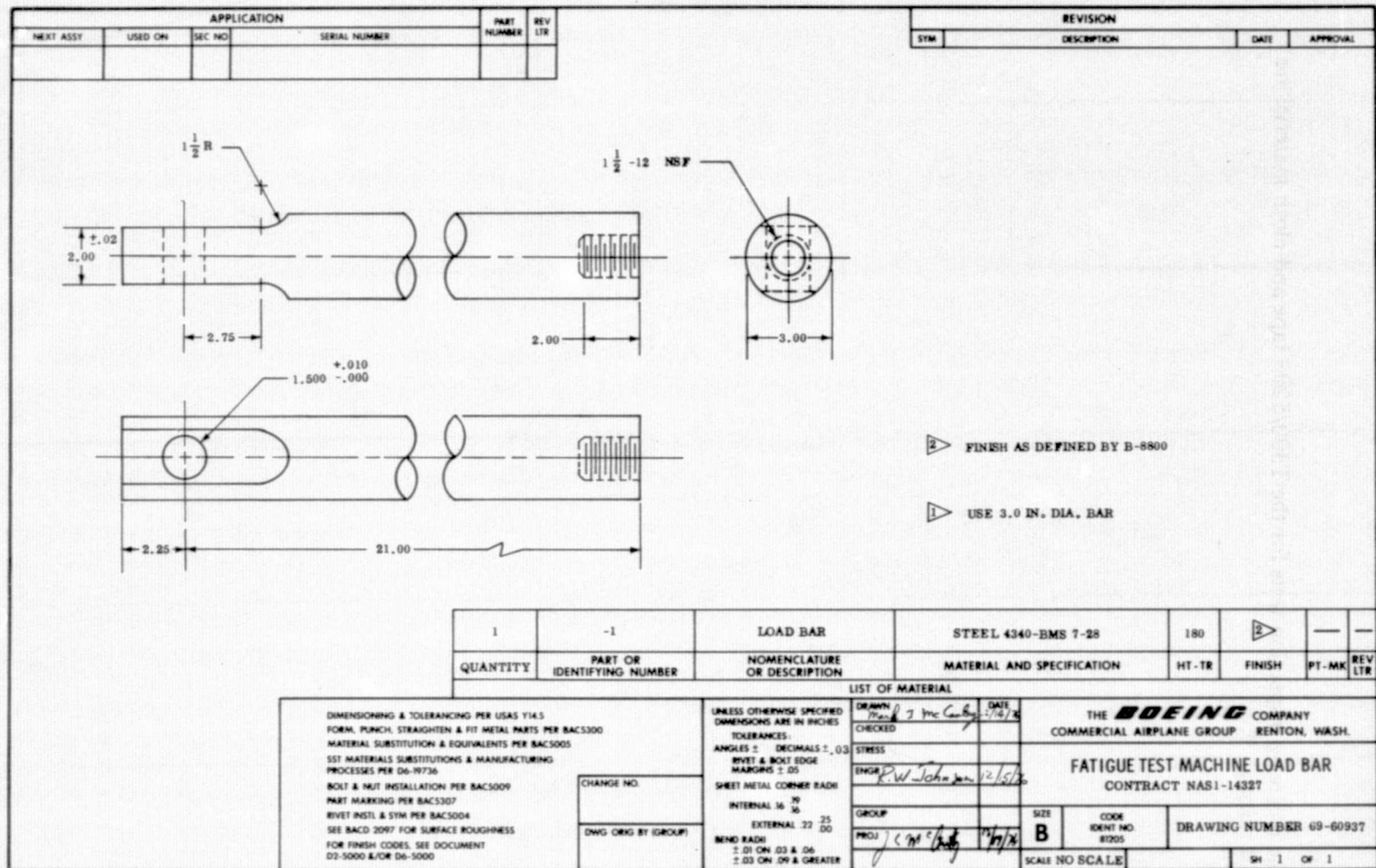


Figure 28.—Fatigue Test Machine Load Bar

APPENDIX C

RECEIVING INSPECTION TEST RESULTS

The results of the receiving inspection tests for the T300/5209 tape and cloth material are shown in tables 7 through 9.

Table 7.—Tension Receiving Inspection Test Data

Data Sheet Mechanical Properties								
Title: 5209/T300 tape and fabric tests					Test:	Tension		
					Date:	6/8/76		
Specimen no.	Test temp, °F	Dimensions			Ult load, kN (lbf)	Ult stress, MPa (psi)	Modulus GPa (psi x 10 ⁶)	Remarks
		Thickness mm (in.)	Width, mm (in.)	Area, mm ² (in. ²)				
T-1	R.T.	1.11 (0.0436)	25.43 (1.0012)	28.16 (0.043652)	14.01 (3150)	497.66 (72 160)	54.56 (7.911)	Tape orientation = (0°/±45°/90°/±45°/0°); 8 plies, 63.79% volume fraction (V _f); Avg stress = 484.9 MPa (70 310 psi); Avg modulus, 51.91 GPa (7.527 x 10 ⁶ psi)
-2		1.10 (0.0435)	25.42 (1.0009)	28.09 (0.043539)	13.17 (2960)	468.94 (67 996)	55.41 (8.035)	
-3		1.11 (0.0438)	25.41 (1.0003)	28.26 (0.043813)	13.57 (3050)	480.07 (69 610)	49.71 (7.208)	
-4		1.12 (0.0439)	25.43 (1.0010)	28.35 (0.043944)	13.97 (3140)	492.83 (71 460)	47.97 (6.955)	
*								
F-1	R.T.	1.33 (0.0522)	25.48 (1.0031)	33.78 (0.052362)	14.46 (3250)	428.07 (62 070)	53.48 (7.755)	Fabric orientation = (0°/45°/2/0°); 4 plies, 64.39% V _f ; Avg stress, 422.1 MPa (61 200 psi); Avg modulus, 53.46 GPa (7.752 x 10 ⁶ psi)
-2		1.31 (0.0516)	25.45 (1.0018)	33.35 (0.051693)	15.48 (3480)	464.28 (67 320)	55.30 (8.019)	
-3		1.32 (0.0518)	22.83 (0.8988)	30.04 (0.051738)	13.26 (2980)	397.24 (57 600)	51.85 (7.518)	
-4		1.31 (0.0515)	25.46 (1.0024)	33.31 (0.051624)	13.12 (2950)	394.07 (57 140)	52.39 (7.596)	
-5		1.32 (0.0520)	25.42 (1.0006)	33.57 (0.052031)	14.32 (3220)	426.83 (61 890)	54.28 (7.871)	
Tape—batch 1527, roll 1 Fabric—batch 4, roll 2								

*-5 specimen had premature grip failure.

Table 8.—Flexure Receiving Inspection Test Data

Data Sheet Mechanical Properties								
Title: 5209/T300 tape and fabric tests					Test: Flexure			
					Date: 6-9-76			
Specimen no.	Test temp, °F	Dimensions			Ult load, kN (lbf)	Ult stress, MPa (psi)	Modulus, GPa (psi x 10 ⁶)	Remarks
		Thickness, d, mm (in.)	Width, b, mm (in.)	bd^2 , mm ³ (in. ³)				
T-1	R.T.	2.49 (0.0981)	12.73 (0.5010)	79.01 (0.0048214)	1.152 (259)	1667.10 (241 730)	114.95 (16.667)	Tape unidirectional; 18 plies, 63.77% V _f ; Span, 76.2 mm (3 in.); Avg stress, 1643.79 MPa (238 350 psi); Avg modulus, 115.17 GPa (16.7 x 10 ⁶ psi)
-2		2.57 (0.1010)	12.68 (0.4993)	83.47 (0.0050934)	1.161 (261)	1590.28 (230 590)	113.70 (16.487)	
-3		2.48 (0.0978)	12.72 (0.5007)	78.48 (0.0047891)	1.112 (250)	1620.07 (234 910)	114.95 (16.668)	
-4		2.40 (0.0943)	12.73 (0.5013)	73.05 (0.0044578)	1.052 (236.5)	1646.48 (238 740)	114.32 (16.576)	
-5		2.36 (0.0931)	12.74 (0.5017)	71.26 (0.0043485)	1.057 (237.5)	1694.97 (245 770)	117.93 (17.100)	
F-1	R.T.	2.52 (0.0994)	12.73 (0.5010)	81.11 (0.0049501)	0.645 (145)	909.10 (131 820)	68.39 (9.917)	Fabric orientation = (0°/90°); 8-ply, 65.72% V _f ; Span 76.2 mm (3 in.); Avg stress, 886.76 MPa (128 580 psi); Avg modulus, 68.27 GPa (9.899 x 10 ⁶ psi)
-2		2.52 (0.0993)	12.75 (0.5018)	81.08 (0.0049480)	0.625 (140.5)	881.24 (127 780)	68.91 (9.992)	
-3		2.53 (0.0997)	12.75 (0.5018)	81.74 (0.0049879)	0.656 (147.5)	917.72 (133 070)	69.34 (10.054)	
-4		2.54 (0.0999)	12.74 (0.5014)	81.99 (0.0050040)	0.670 (150.5)	933.38 (135 340)	68.14 (9.880)	
-5		2.55 (0.1002)	12.74 (0.5014)	82.50 (0.0050341)	0.572 (128.5)	792.21 (114 870)	66.58 (9.654)	
Tape—batch 1527, roll 1 Fabric—batch 4, roll 2								

Table 9.—Short Beam Shear Receiving Inspection Test Data

Data Sheet Mechanical Properties							
Title: 5209/T300 tape and fabric tests				Test: Short beam shear Date: 6-8-76			
Specimen no.	Test temp, °F	Dimensions			Ult load, kN (lbf)	Ult stress, MPa (psi)	Remarks
		Thickness, mm (in.)	Width, mm (in.)	Area, mm ² (in. ²)			
T-1	R.T.	2.39 (0.0942)	6.48 (0.2552)	15.51 (0.024040)	2.07 (464.5)	99.93 (14 490)	18-ply unidirectional tape; Span 9.9 mm (0.39 in.); 63.77% V _f ; Avg stress, 100.69 MPa (14 600 psi)
-2		2.36 (0.0929)	6.44 (0.2537)	15.21 (0.023569)	2.02 (454.5)	99.72 (14 460)	
-3		2.38 (0.0936)	6.47 (0.2546)	15.37 (0.023831)	2.10 (472.0)	102.48 (14 860)	
-4		2.40 (0.0945)	6.47 (0.2547)	15.53 (0.024069)	2.08 (467.0)	100.34 (14 550)	
-5		2.37 (0.0933)	6.45 (0.2538)	15.28 (0.023680)	2.06 (462.0)	100.90 (14 630)	
F-1	R.T.	2.55 (0.1003)	6.46 (0.2543)	16.46 (0.025506)	1.37 (307.5)	62.34 (9 040)	Fabric orientation = (0°/90°) 8-ply, 65.72% V _f . Span 9.9 mm (0.39 in.); Avg stress, 64.41 MPa (9 340 psi)
-2		2.56 (0.1008)	6.43 (0.2532)	16.47 (0.025523)	1.43 (321.5)	65.17 (9 450)	
-3		2.56 (0.1007)	6.43 (0.2532)	16.45 (0.025497)	1.43 (321.5)	65.24 (9 460)	
-4		2.52 (0.0991)	6.45 (0.2539)	16.23 (0.025161)	1.38 (310.0)	61.86 (8 970)	
-5		2.51 (0.0988)	6.46 (0.2545)	16.22 (0.025145)	1.46 (327.5)	67.38 (9 770)	
Tape—batch 1527, roll 1 Fabric—batch 4, roll 2							

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